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Simulating long-term effects of policies in the agri-food sector: requirements, challenges and recommendations

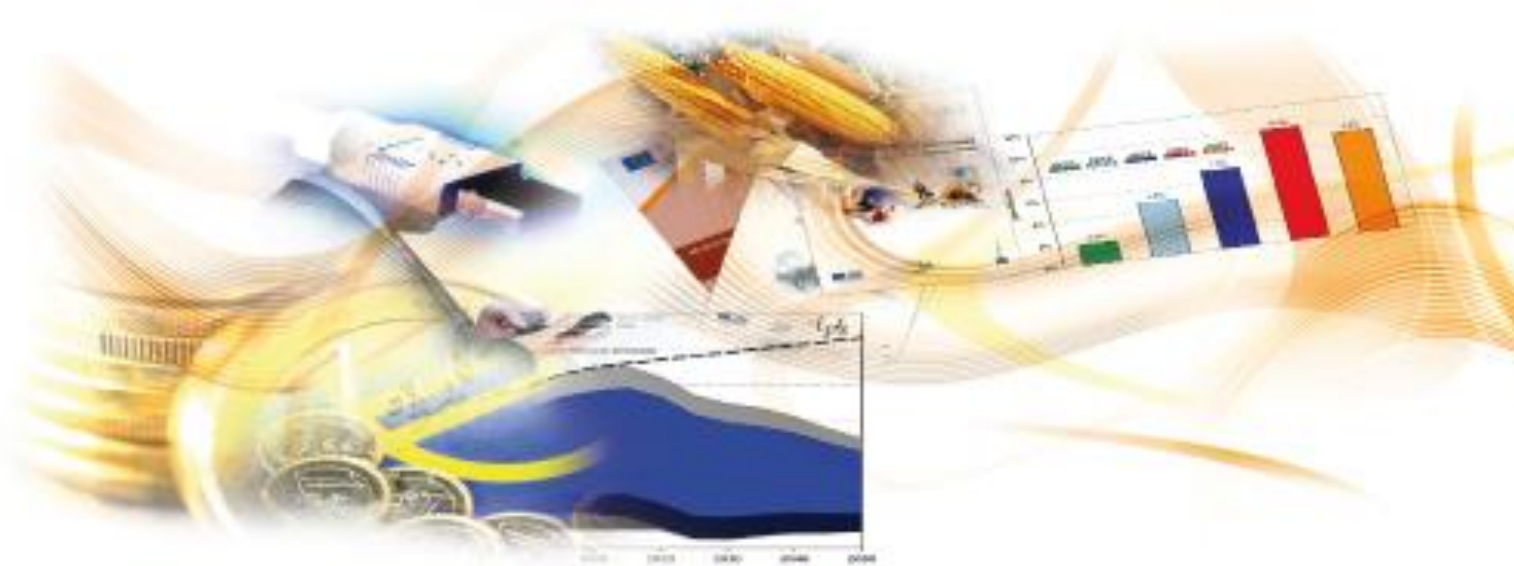
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Preface

Since 2006 the European Commission's Joint Research Centre, Institute for Prospective and Technological Studies (JRC-IPTS) is building, maintaining and applying an integrated Modelling Platform for Agro-economic Commodity and Policy Analysis (iMAP). The iMAP initiative has developed into a policy support-oriented platform with access to a number of multi-commodity multi-regional models (MCMR), mainly Partial Equilibrium (PE) and Computable General Equilibrium (CGE) models, which are used in stand-alone mode or in combination.¹ The MCMR are used as analytical tools for the assessment of impacts of alternative agricultural, trade, environmental and structural policies on the agricultural and food sectors. Most of these models have been conceived as medium term policy tools with a time horizon of 10-15 years. There is, however, an increasing interest in questions related to food security, natural resources and climate change focusing on a longer time horizon of about 40 years, which requires a more specifically tailored analysis to capture the 'drivers' which will shape world agricultural and food markets. To assess the requirements and challenges entailed with the simulation of long-term issues in the agri-food sector the JRC-IPTS launched the project "Methodological requirements of a modelling tool for simulation of long-term (2050) effects of policies affecting the agricultural and food sectors". The project was conducted under the auspices of the ENgAGE (Expert Network for Agro-Economic modelling) framework contract 152039-2010 A08-NL between the JRC-IPTS and the Dutch Agricultural Economic and Research Institute (LEI, part of Wageningen University), The Hague, The Netherlands.

This report summarises the information gathered within the project, mainly drawing on (workshop) discussions and several technical notes written by participants of the project. The following persons contributed to the project:

Maciej Bukowski: Economist and Director of the Institute for Structural Research in Warsaw, Poland. Maciej contributed to the development of a large scale, multi-sector DSGE model of the Polish economy used for analysing the macroeconomic impact on Polish economy of the diversified package of about 120 different GHG mitigation levers.

Piero Conforti: Economist at the Global Perspective Studies Team part of the Agricultural Development Economics Division of the Food and Agriculture Organization of the United Nations (FAO), Rome, Italy. Piero is responsible for the activities on partial equilibrium (PE) developments for long-term analysis.

Peter Dixon: Professor at Monash University, Clayton, Australia. Peter is known internationally for his work on CGE modelling. He created the 'ORANI' and

¹Detailed information on iMAP can be found in M'barek et al. (2012).

'MONASH' models and more recently he has led the development of the 'USAGE' model.

Alexandre Gohin: Professor and research director at the French National Institute for Agricultural Research, INRA-Rennes, France.

Andrey Krasovskii: Research scholar at the International Institute for Applied Systems analysis (IIASA) in Laxenburg, Austria. Andrey is an expert on mathematical modelling and dynamic optimization. He contributed to develop methods for solving optimal control problems with infinite horizon.

Jerzy Michalek: an Agricultural Economist, Senior Consultant and advisor to various international organizations (European Commission, World Bank, FAO, etc.) and governments in several CEE countries, with high level of expertise in EU agricultural, trade- and structural policies, rural development programmes; and excellent knowledge of advanced econometric evaluation methods.

Hans van Meijl: Senior Researcher and Head of Department International Policy at the Agricultural Economics Research Institute (LEI), Den Haag, The Netherlands.

Dominique van der Mensbrugghe: Senior Economist and responsible for the Global Perspective Studies Team part of the Agricultural Development Economics Division of the FAO, Rome, Italy. Dominique is a leading expert in the area of CGE modelling. He developed the 'Environmental Impact and Sustainability Applied General Equilibrium' (ENVISAGE) model used at the World Bank.

Axel Tonini: at the time of editing this report he was researcher at the Agricultural Economics Research Institute (LEI, part of Wageningen University), Den Haag, The Netherlands. He has been previously working on ex-ante impact analyses using several partial equilibrium models (Common Agricultural Policy SIMulation, European SIMulation, IRRI Global Rice Model) and he also has expertise on applied econometric methods. He is currently Scientific Collaborator at the Swiss Federal Agricultural Office, Bern, Switzerland.

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Michael Wickens: Professor at the University of York, York, United Kingdom. Michael's interests focus on macroeconomics and finance, the connections between the two, and in developing new analytical and empirical tools. He is author of the book entitled 'Macroeconomic Theory: A Dynamic General Equilibrium Approach'.

Heinz-Peter Witzke: Senior Agricultural Economist at the European Centre for Agricultural, Regional and Environmental Policy Research (EuroCARE), Bonn, Germany. Heinz Peter contributes to the development of the CAPRI model that has been intensively used as a reference PE model within the EU.

Geert Woltjer: Senior Economist at the Agricultural Economics Research Institute of The Netherlands (LEI, part of Wageningen University), Den Haag, The Netherlands. Geert contributed to the development of the MAGNET and he is currently focusing on implementing the biofuel sector.

Additional contributions and the editing of the document were carried out by the following former and current colleagues from the JRC-IPTS: Axel Tonini, Jerzy Michalek, Robert M'barek, Jacques Delincé, Thomas Fellmann, and George Philippidis.

This report is testament to the combined efforts of a number of consulted experts and authors and, as such, its content inevitably reflects the value judgements of each of those contributors. Consequently, it should be noted that the findings from this report are not intended in any way as a definitive and exhaustive account of the topic of long term modelling. This work merely serves as an initial point of reference into what will undoubtedly become a more prominent field of research in the coming years.

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Abbreviations

AgMIP	Agricultural Model Intercomparison and Improvement
CAP	Common Agricultural Policy
CAPRI	Common Agricultural Policy Regional Impact Analysis
CAPSIM	Common Agricultural Policy SIMulation
CDE	Constant Difference of Elasticity
CET	Constant elasticity of transformation
CGE	Computable General Equilibrium
DCGE	Dynamic Computable General Equilibrium
DG AGRI	Directorate General 'Agriculture and Rural Development'
DG ECFIN	Directorate General 'Economic and Financial Affairs'
DSGE	Dynamic Stochastic General Equilibrium
EC	European Commission
EDGAR	Emissions Database for Global Atmospheric Research
ENgAGE	Expert Network for Agro-Economic Modelling
ENVISAGE	Environmental Impact and Sustainability Applied General Equilibrium
EU	European Union
EU-12	12 EU Member States of the 2004 and 2007 enlargements
EU-15	15 EU Member States before May 2004
EU-25	25 EU Member States after 2004 enlargement
EU-27	27 EU Member States after 2007 enlargement
EuroCARE	European Centre for Agricultural, Regional and Environmental Policy Research
FAO	Food and Agriculture Organization of the United Nations
FAPRI	Food and Agricultural Policy Research Institute, USA
FOC	first order equilibrium conditions
GDP	Gross Domestic Product
GHG	Greenhouse Gas Emissions
GLOBIOM	GLObalBIomass Optimization Model
GMO	Genetically modified organism
GTAP	Global Trade Analysis Project
ICT	Information and communication technology
IIASA	International Institute for Applied Systems analysis
ILUC	Indirect Land Use Change
iMAP	integrated Modelling Platform for Agro-economic Commodity and Policy Analysis

INRA	French National Institute for Agricultural Research
IPSC	Institute for the Protection and Security of Citizen
IPTS	Institute for Prospective Technological Studies
JRC	Joint Research Centre
LEI	Landbouw-Economisch Instituut (Agricultural Economics Institute)
LES	Linear Expenditure System
LUC	Land Use Change
MAGNET	Modular Agricultural GeNeral Equilibrium Tool
MCMR	Multi-commodity multi-regional
NUTS	Nomenclature of Territorial Units for Statistics
OCT	Optimal Control Theory
OECD	Organisation for Economic Co-operation and Development
PE	Partial Equilibrium
PRIMES	PRIMES Energy System
RED	Renewable Energy Directive
REDD	Reducing Emissions from Deforestation and Forest Degradation
SAM	Social Accounting Matrix
VAR	Vector autoregression
WTO	World Trade Organization

1 Introduction

The link between rapid population growth and economic development on the one hand, and the unsustainable depletion of the earth's natural resources and its concomitant impacts on the environment on the other hand, is a well-established policy concern. In the context of agriculture and food, these 'drivers' are key factors behind our ability to feed the global population, although we are still some way from understanding the role each of these drivers will play in influencing global food markets.

In an attempt to inform ourselves on the lasting impacts of these types of questions, multi-commodity multi-regional models (MCMR) are employed to carry out simulations for the assessment of impacts of alternative agricultural, trade, environmental and structural policies on the agricultural and food sectors. However, these models are traditionally used to deal with medium term time horizons and in many cases, are not adequately equipped to capture the modelling specificities and market developments required to undertake a longer term market analysis. Consequently, new tools of analysis are required, or at very least, a fundamental rethink of some of the existing methodologies in order to tackle the challenge of 'long term modelling'. Whilst the key aim of this report is to shine some light on the current state of play with respect to the current suite of policy models within the iMAP platform, section 1.1 provides the reader with a brief overview of some of these aforementioned long term challenges.

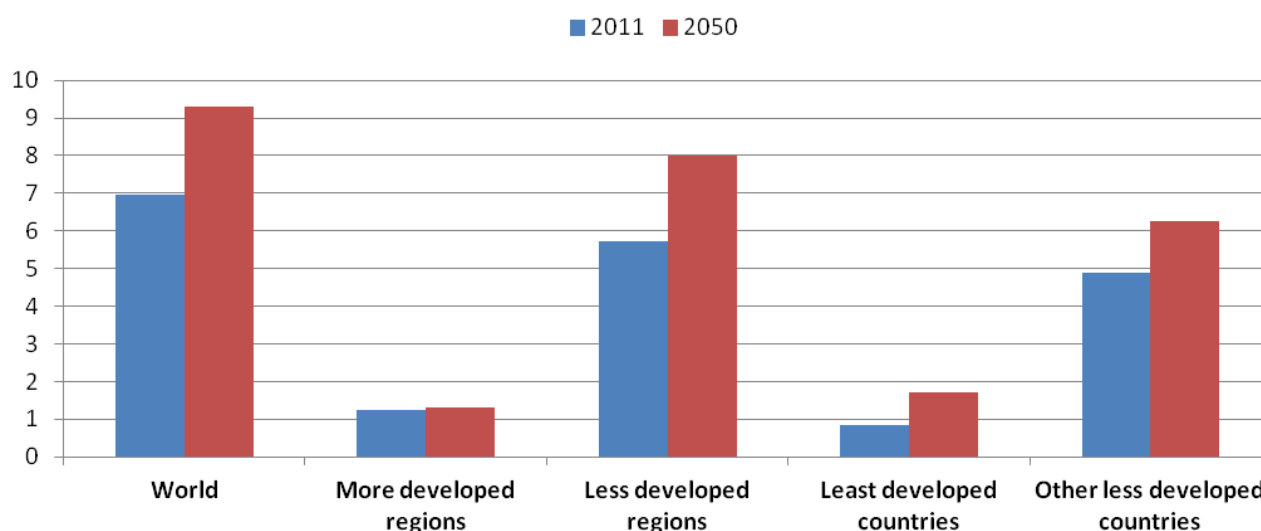
1.1 Feeding a growing world sustainably

A first major factor influencing the development of agricultural and food markets in the long-term is population growth. The human population reached 7 billion in 2011 and even though its rate of growth over the next 50 years is expected to slow down compared with the last 50 years, it is still likely to pass 9.3 billion people by 2050 according to the medium variant of the United Nation's projections. Thus, the world needs to find resources to feed an additional 2.3 billion persons by 2050. It should be noted that the UN's medium variant assumes a decline in fertility, although if this assumption were not to transpire and fertility rates remain at current levels, world population in 2050 is projected to increase to 10.9 billion (UN, 2011).

Regarding the rise in population it is also important to consider its distributional implications as it is made up of slowdowns or stagnation in population growth in some countries and rapid growth in others. More specifically, almost no population increase is expected in more developed, high income regions, whilst the population of the less developed regions is projected

to increase from 5.7 billion in 2011 to 8 billion in 2050, with the population of least developed countries more than doubling to over 1.7 billion. Thus, by 2050 only about 14% of the world population is projected to live in more developed regions, whereas 86% will live in less developed regions, including about 19% in the least developed countries (UN, 2011; cf. Figure 1). Consequently, in the next 40 years it is anticipated that even more aggressive use of finite resources will be concentrated in the 'hotspot' areas of Africa and Asia.

Figure 1: World Population Prospects



More developed regions: Europe, Northern America, Australia/New Zealand and Japan.

Less developed regions: All regions of Africa, Asia (except Japan), Latin America and the Caribbean plus Melanesia, Micronesia and Polynesia.

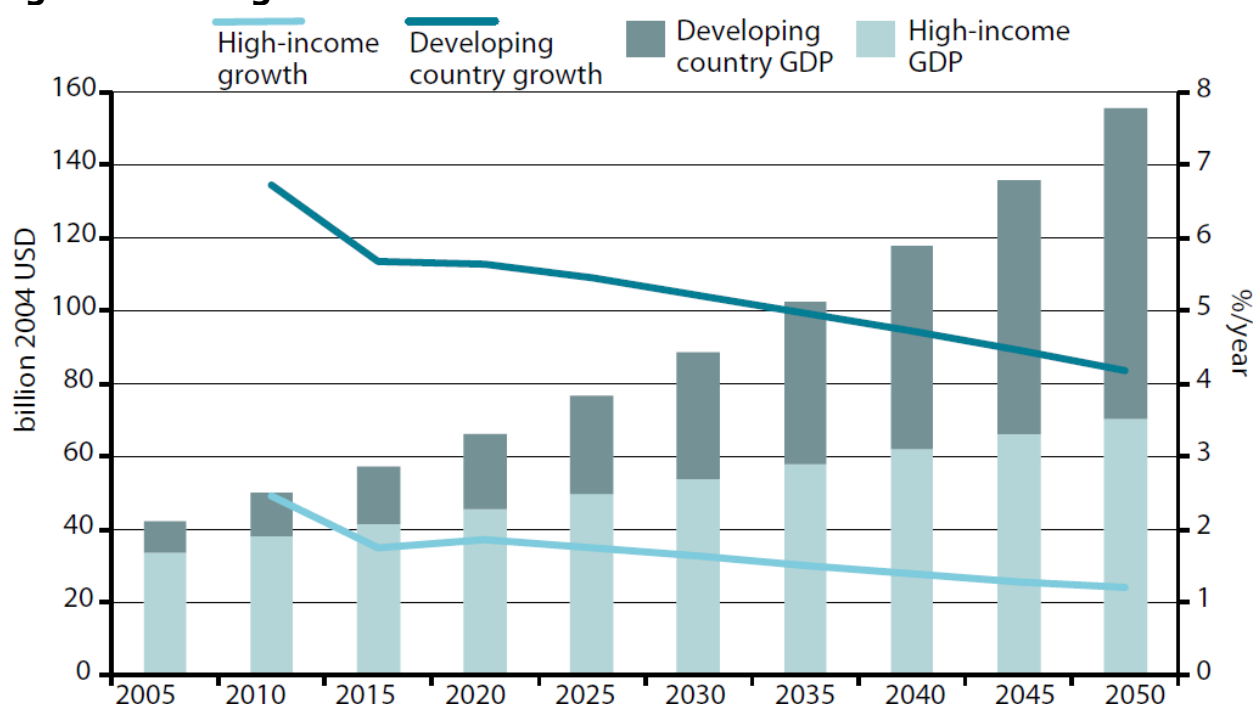
Least developed countries: total of 48 countries, 33 in Africa, 9 in Asia, 5 in Oceania, 1 in Latin America and the Caribbean.

Other less developed countries: less developed regions excluding the least developed countries.

Source: UN (2011)

Population dynamics will also have implications for (*inter alia*) the level of urbanisation which has long term implications for agro-food markets. It is estimated that 60% of the world's population will live in cities by 2030 which implies an increased pressure on the provision of adequate basic services such as sanitation and transport. In developing countries undergoing rapid urbanisation, the adequate provision of these services will become particularly acute. In terms of food security, the supply chain must be able to address the logistical challenge of safeguarding an efficient distribution to highly concentrated population areas in the face of potentially inadequate public services (Satterthwaite et al., 2010).

Besides population growth, economic development will also have a key role to play on the agricultural and food sector. Based on GDP data and projections of the World Bank, Mensbrugghe et al. (2011) calculated that GDP in developing countries is expected to grow faster than in developed countries (cf. Figure 2). As a consequence per capita incomes will converge in relative terms; however absolute gaps are projected to remain substantial.

Figure 2: GDP growth scenario


Source: van der Mensbrughe et al., (2011, p.205)

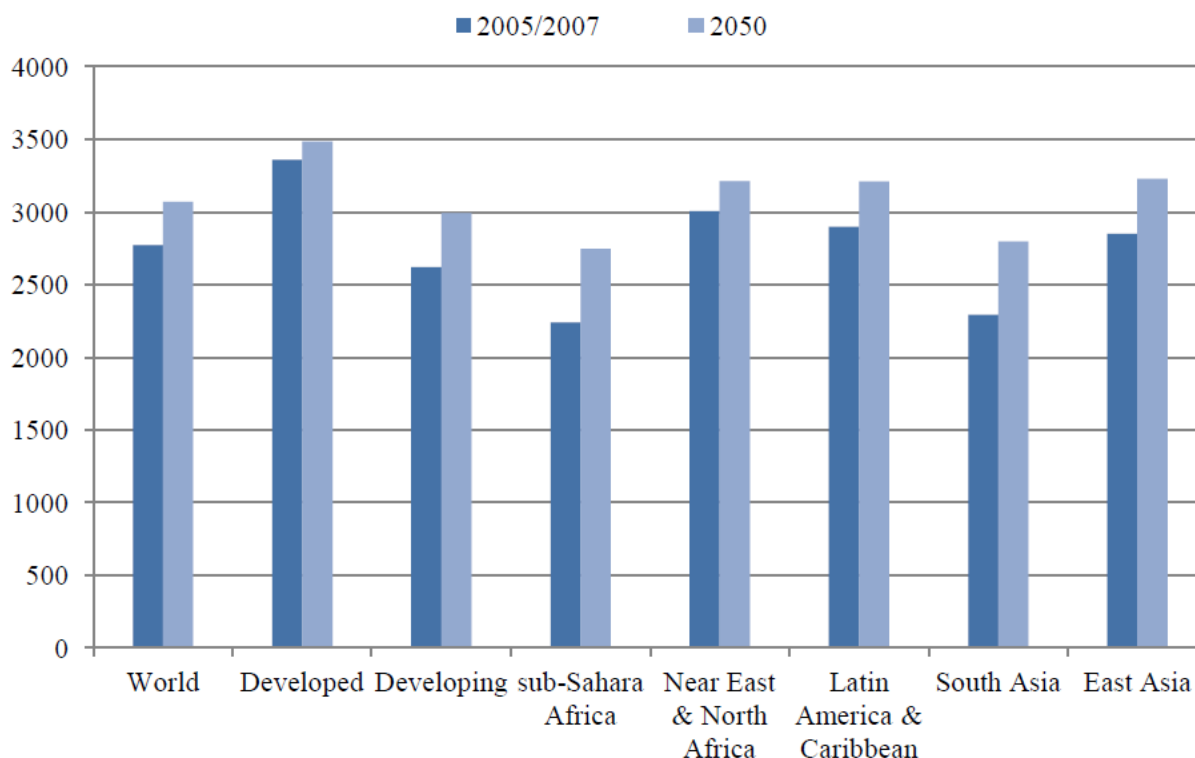
Due to the rise in income there will be a substantial portion of the world population that will increase its food consumption (cf. Table 1). In addition, economic growth is usually accompanied by a change in dietary intensity (Popkin, 2002) and a general shift from a diet that is largely based on grains to one that relies more on meat- and dairy-based proteins (Cirera and Masset, 2010; Kearney, 2010; cf. Figure 3).

Table 1: Per capita food consumption (kcal/person/day)

	Historical Data				Projections		
	1969/ 1971	1979/ 1981	1990/ 1992	2005/ 2007	2015	2030	2050
World	2373	2497	2627	2772	2860	2960	3070
Developing countries	2055	2236	2433	2619	2740	2860	3000
Sub-Saharan Africa	2031	2021	2068	2238	2360	2530	2740
Near East / North Africa	2355	2804	2983	3007	3070	3130	3200
Latin America and Caribbean	2442	2674	2672	2898	2990	3090	3200
South Asia	2072	2024	2250	2293	2420	2590	2820
East Asia	1907	2216	2497	2850	3000	3130	3220
Developed countries	3138	3223	3257	3360	3390	3430	3490

Source: Alexandratos and Bruinsma (2012, p.23)

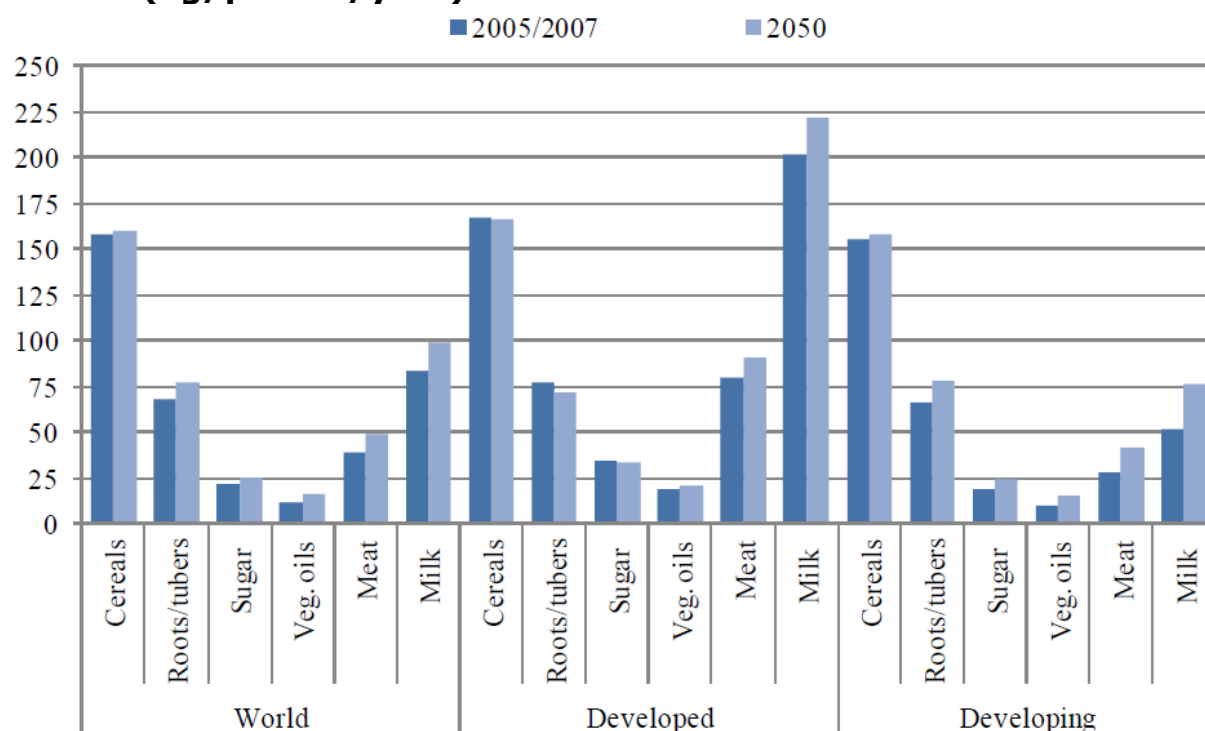
Figure 3: Per capita food consumption (kcal/person/day)



Source: Alexandratos and Bruinsma (2012, p.4)

Population growth, increases in per capita consumption and changes in diet are among the main drivers of demand for agricultural products. Yet, global demand for agricultural products is projected to annually increase by about 1.1% to 2050, which is considerably less than the 2.2% in the last four decades (Alexandratos and Bruinsma, 2012). This slowdown in global food demand is, on the one hand, attributable to the lower expansion rate of the global population and to only gradual income gains and persistence of poverty in some developing countries. On the other hand, the transition to livestock based diets is considered as largely completed in most of the developed countries, whilst some developing countries are also expected to be rather slow in adopting levels of meat consumption typically found in western diets (or they are rather unlikely to do so in the foreseeable future due to religious factors, like India with regard to beef meat and Muslim countries regarding pig meat) (Kearney, 2010; Alexandratos and Bruinsma, 2012). Even though differences in the consumption level of livestock products are expected to remain large between developed and developing countries (cf. Figure 4), the expected consumption increases in both need to be satisfied.

Figure 4: Food consumption per capita, major commodities (kg/person/year)



Source: Alexandratos and Bruinsma (2012, p.5)

As has been seen, population growth, economic development and growing meat consumption will drive both the pattern and distribution of food supply. It is far from clear whether agricultural productivity improvements will be able to satisfy the increased demand. On a positive note, food production has risen substantially over the last half century due to improvements in irrigation, fertilisers and expansions in land usage (see e.g. Jaggard et al., 2010; Thornton, 2010). Notwithstanding, Alexandratos and Bruinsma (2012) estimate that global agricultural supply in 2050 needs to be 60% higher compared to 2005/2007 in order to meet demand.

A key barrier to achieving this target is climate change. Anthropogenic activity via the burning of fossil fuels has been a driving factor behind the sustained increase in global temperatures over the last 100 years. The results of this have become evident in terms of increasing sea temperatures, melting polar ice caps and increased sea levels, whilst the frequency and intensity of extreme weather conditions such as heat waves, drought, heavy storms and flooding presents a constant threat to the farming ecosystem. It is estimated that further global warming of between 1.5-2.5°C beyond today's levels would also put 20-30% of plant and animal species at increased risk of extinction (IPCC, 2007).

In this context, the potential for agricultural production to meet projected increases in demand is far from certain. Agricultural production is a large user

of fresh water supplies, whilst suitable irrigated agricultural land is threatened by soil erosion, nutrient loss and salination. Furthermore, the impacts of climate change on the pattern of farm production throughout the world owing to heterogeneous temperature changes in different regions, introduces considerable uncertainty to global supply patterns and distribution chains (IPCC, 2007; Nelson et al., 2010). Accordingly, aside from the need to impose global solutions in the form of mitigation strategies to reduce greenhouse gas emissions (to which agriculture contributes considerable non-CO₂ emissions), farming practice in the 21st century will also be expected to adopt appropriate 'adaptation' strategies to counter the eventuality of rising temperatures and their expected negative impacts on productivity.

More general concerns also arise regarding the sustainability of global agricultural intensification in the context of deforestation, land degradation and water pollution (Nellemann et al., 2009; Royal Society, 2009; Nature, 2010; Garnett and Godfray, 2012). Finally, policy mandated non-food uses of finite land resources (i.e., first generation biofuels) present additional supply constraints. In the context of these issues, some commentators (e.g. Nellemann et al., 2009) take a rather more pessimistic line, suggesting that if current trends continue, food production would be some 25% below consumption by 2050. Other studies (see e.g. IAASTD, 2009; Jaggard et al.; 2010; Conforti, 2011) present a more optimistic view, where on a global level it is considered that enough production potential could be activated to meet the increasing demand for agricultural commodities via the adoption of improved agricultural methods (e.g., better rain-fed and irrigation management techniques; improved pesticides and herbicides) or even higher yielding strains of crops. One such study (Alexandratos and Bruinsma, 2012) presents detailed forecasts for expected growth rates in agricultural production and consumption. Interestingly, owing to different supply (e.g., climate, soils, infrastructure) and demand (e.g., population, economic development) conditions, rates of growth differ significantly between countries and country groups (cf. Table 2).

As can be seen from Table 2, in previous decades production growth rates in developing countries have been generally slightly below those of consumption and this trend is projected to continue up to the year 2050, indicating an increasing need for agricultural food imports from developed countries. It has to be kept in mind that while production increases in developed countries could potentially satisfy the needs of developing countries, this would not necessarily assure secure access to food. Thus, even though the necessary global increase in agricultural production for meeting demand is less than in previous decades, the required growth might not be possible to achieve without national and international policy incentives (see e.g. IAASTD, 2009; Godfray et al., 2010).

Table 2: Annual growth rates of agricultural demand and production (%)

	Demand (all commodities, all uses)			Supply (all food and non-food commodities)		
	1980-2007	2005/2007-2030	2030-2050	1980-2007	2005/2007-2030	2030-2050
World	2.2	1.4	0.8	2.1	1.3	0.8
Developing countries	3.6	1.7	0.9	3.5	1.6	0.9
- excl. China	2.9	1.9	1.2	2.9	1.8	1.2
Sub-Saharan Africa	3.4	2.6	2.1	3.2	2.5	2.1
Near East/North Africa	2.8	1.7	1.1	2.8	1.6	1.2
Latin America and Caribbean	2.6	1.7	0.6	2.9	1.7	0.8
South Asia	3.0	2.0	1.3	2.9	1.9	1.3
East Asia	4.4	1.4	0.5	4.2	1.3	0.5
- excl. China	2.9	1.6	0.9	2.7	1.5	0.9
Developed countries	0.3	0.6	0.2	0.2	0.7	0.3

Source: Alexandratos and Bruinsma (2012)

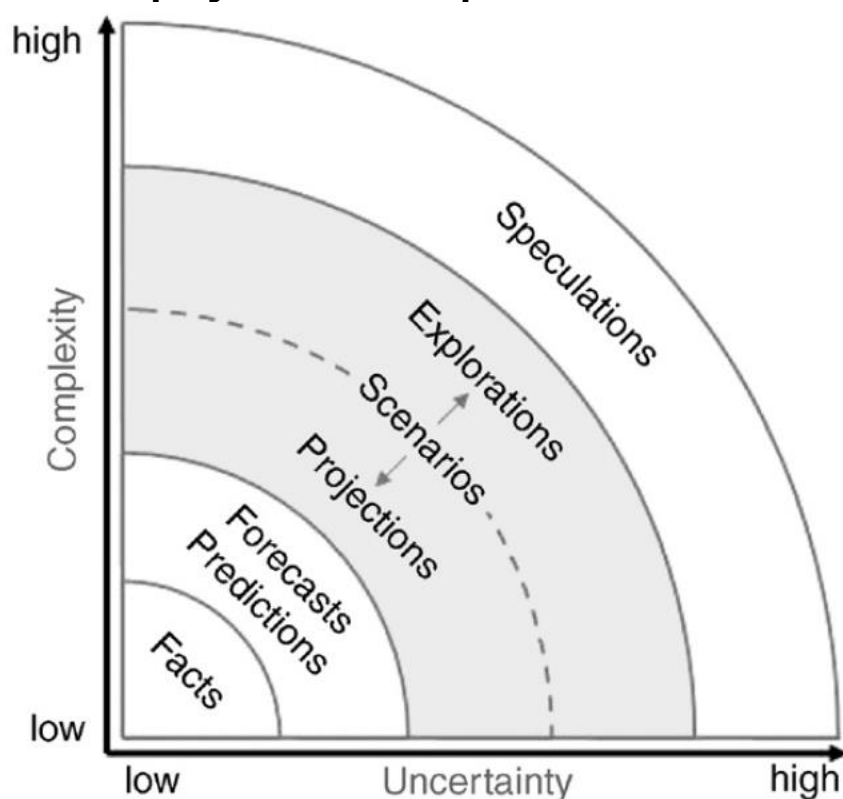
The issues briefly outlined, although not exhaustive, clearly demonstrate the need to increase agricultural production and improve food distribution to meet projected demand in the next decades, while at the same time coping with environmental and sustainability challenges. Consequently, there is a need for detailed analysis of how general developments and policies affect the agricultural and food sector in the long-term. This report assesses the requirements and challenges entailed with capturing and simulating the long-term issues in the agri-food sector.

1.2 Projecting future paths

The way the future is assessed in complex systems depends on how well the complexity of the system is understood and how certain the future developments of key drivers are. The issues and challenges outlined in section 1.1 illustrate that any analysis of long-term impacts of general developments and policies on the agricultural and food sector is apparently afflicted with both substantial uncertainty and complexity. Thus, in the context of this report we are dealing with scenario analysis, i.e. modelling approaches that produce projections, not forecasts, of future paths. Differences between facts,

forecasts, projections and speculations with regard to complexity and uncertainty are depicted in Figure 5.

Figure 5: Complexity and uncertainty in the context of facts, forecasts, projections and speculations



Source: Zurek and Henrichs (2007, p.1284)

The literature provides various definitions for scenarios, e.g. the IPCC (2007) describes a scenario as a “coherent, internally consistent and plausible description of a possible future state of the world” and the EEA (2005) as a “plausible description of how the future may unfold based on ‘if-then’ propositions”. There are different purposes for developing and analysing scenarios, but in the context of this report two main purposes for long-term modelling, often interrelated and handled by the same tool, but nonetheless distinguishable, can be identified. The first is to prepare ‘baseline projections’ or ‘benchmark scenarios’ on agriculture for a long-term horizon, taking into account those drivers that may be expected to shape future agriculture. On the demand side, shifts are expected to occur owing to population change and income growth, whilst other ‘non-economic’ factors like urbanisation and cultural differences also play a role in identifying taste shifts. From the perspective of supply, advances in the state of technology (environmental friendly - productivity growth) and its diffusion among farmers will be crucial, whilst the evolution of the world's natural environment from climate change, salinization, area loss to built-up areas or desertification, will all play a role in shaping the future path of (inter alia) agricultural production. Moreover, the

depletion of the earth's fossil fuels is expected to maintain the upward trend of energy prices. Indeed, the oil price is volatile and determines to a large extent the development of the integration between the energy and agricultural markets. Given the high level of uncertainty related to all these drivers often more scenarios are defined in line with some crucial uncertainties such as profit oriented versus sustainability and regionalisation versus internationalisation (see e.g. IPCC, 2000; EUruralis; 2013).

Baseline scenarios are often used as a reference (benchmark) for 'what-if'-scenarios, which leads to the second purpose for developing and analysing scenarios: investigate variations from 'business as usual' projections or benchmark scenarios that typically involve policy scenarios, but potentially also other sensitivity analyses. The kind of policy scenarios for the long-term will be different from typical agricultural policy studies for the medium-term horizon. The investigation of moderate changes in the forms of income support to agriculture, say via some tariffs, TRQs, or premiums will be largely uninteresting for the long-term because these details are likely to change several times in the coming decades in ways that cannot be predicted years ahead. Furthermore small policy shifts would trigger such moderate impacts that these would be considered indistinguishable from the 'noise' in the projections due to the uncertainty in parameters and other exogenous impacts. Instead, it might be more interesting to look at rather fundamental shifts in agricultural policy, say a complete or almost complete unilateral or multilateral liberalisation or long-term policy scenarios that fall into the realm of renewable energy policies, R&D policies, environmental or climate policies. Equilibrium models with an explicit coverage of global land use may inform about the consequences of policies to set aside a certain percentage of EU land for biodiversity goals or to greatly increase the share of organic production in the EU. Dry land may increase food price volatility and for food security a big land reserve can help in mitigating those effects. Other policy questions with great long-term relevance could be whether European consumers should be pushed by public information campaigns to reduce their meat consumption or whether India should fight against Western consumption habits spreading among its population. Other relevant long-term scenarios may address the impact of policy support or restraint in the face of specific technological options (GMOs, cloning, precision farming, etc.).

1.3 Structure of the report

The report is structured as follows: Chapter 2 provides a short description of the selected approaches for long-term modelling. In line with the current modelling capabilities in iMAP, the two core methodological approaches are PE and CGE models. In addition, Dynamic Stochastic General Equilibrium (DSGE) and Optimal Control Theory (OCT) approaches are taken into account. Chapter

3 outlines the selected major methodological issues that have to be tackled when simulating long-term effects of policies in the agri-food sector. Crucial aspects for long-term analyses are further elaborated and commented on in Chapter 4, and specific examples and recommendations are provided. Chapter 5 presents conclusions.

2 Selected economic model approaches

There are various methodologies and theories that can be considered when addressing long-term projections. However, in line with the current modelling capabilities in iMAP, the focus in this report is set on two core methodological approaches: PE and CGE models. In addition, Dynamic Stochastic General Equilibrium (DSGE) and Optimal Control Theory (OCT) approaches are taken into account.²

2.1 Partial Equilibrium (PE) models

PE models portray the behavioural interactions within one or more economic sectors, whilst treating outcomes in other sectors as exogenous and hence unaffected by changes in the sector(s) depicted. PE models are used to investigate the impact of changes on those sectors most immediately relevant to a problem with no feedback of these impacts from other sectors. The PE models in iMAP focus on the agricultural sector. Increasingly, they also comprise other selected sectors (vegetable oil processing, dairies, biofuel processing, feed concentrate industry) with strong ties to primary agriculture or to the wider economy (e.g. competition for land). The core PE models of iMAP are AGLINK-COSIMO, CAPRI and ESIM, although other models or tools are used to complement or address questions that cannot be treated with these models (M'barek et al., 2012).

The Common Agricultural Policy Regionalized Impact (CAPRI) model has been selected as the reference PE model for this report. The CAPRI model (Britz and Witzke, 2008) is a tool for ex-ante impact assessment of agricultural and international trade policies with a focus on the EU. As an economic partial comparative static equilibrium model for agriculture, its core consists of two interlinked modules: about 280 regional aggregate programming models covering the EU27, Norway and Western Balkans at the NUTS2 level and a global spatial multi-commodity model for agricultural commodities, which together allow calculation of a wide range of economic and environmental indicators. A spatial downscaling component allows impact assessment at the 1x1 km grid level for EU27. CAPRI is written in GAMS and steered by a Graphical User Interface realized in Java. The development and maintenance of CAPRI was mainly financed by the EU's research framework programs based on a suite of research projects coordinated by the Institute for Food and Resource Economics, University of Bonn. Currently major developments of the CAPRI model are taking place under the CAPRI-RD Framework Program 7

² This list should not be considered exhaustive on its own since other methodologies and theories could also be considered when addressing long-term projections.

project (2009-2013). The project links the economic model CAPRI, covering agriculture, with CGE models building on the RegFin model covering all economic sectors. The tool will inform policy makers and the public interested in ex-post and ex-ante impact assessments about consequences of changes in the Common Agricultural Policy (CAP) based on a wide range of economic, social and environmental indicators. A frequently updated list of the current projects carried out using CAPRI is available on the CAPRI model website (www.capri-model.org).

2.2 Computable General Equilibrium (CGE) models

A CGE model is a system of nonlinear simultaneous equations representing the constrained optimising behaviour of all agents within the economy as producers, consumers, factor suppliers, exporters, importers, taxpayers, savers, investors, or government. This means that it depicts the production, consumption, intra-sectoral input and trade of all sectors for one country, a region or even all countries worldwide. The main CGE models used in iMAP are MAGNET, GTAP and GLOBE (M'barek et al., 2012).

The Modular Agricultural GeNeral Equilibrium Tool (MAGNET) has been chosen as the reference CGE model for this report. The MAGNET model that supersedes the former LEITAP model is a modular CGE model that covers the whole economy, including factor markets, and can be used in the analysis of the CAP and rural development, bi- and multilateral trade negotiations, biofuel and renewable energy policies, dietary changes, etc. (see the key LEITAP reference of Meijl et al., 2006). It is a modified version of the global GE model Global Trade Analysis Project (GTAP) (Hertel et al., 1997). The model and its underlying database describe production, use and international trade flows of goods and services, as well as primary factor use differentiated by sectors. Assumptions about population growth, technological progress, and the policy framework are the main drivers of the model's outcome. A major advantage of this model compared to other CGE models available is the possibility to integrate a more detailed representation of the CAP and the agricultural land and labour market specification as used in the 'Scenar2020 I&II' studies for DG AGRI (Nowicki et al. 2007, 2009). Another feature is its flexibility with respect to sectoral and regional aggregation and functional set up. Some of the recently implemented agricultural related policies are a detailed land use supply function (Eickhout et al., 2009), a biofuel energy module (Banse et al., 2008), the implementation of 'REDD' (Reducing Emissions from Deforestation and Forest Degradation, Overmars et al., 2012) and the use of second generation biomass in energy, pellets, transportation fuel and chemicals. The MAGNET model has been used for long-term analyses in the 'OECD Environmental Outlook' (OECD, 2008; 2012), and the Economics of

Ecosystems and Biodiversity (TEEB) study. The MAGNET model is currently in use at the LEI, JRC-IPTS and the Thünen Institute (TI).

2.3 Other methodologies and theories considered

New methodological developments such as Dynamic Stochastic General Equilibrium (DSGE) models and Optimal Control Theory (OCT) explicitly address some of the weakness encountered in standard MCMR models. DSGE models add a dynamic and stochastic component to CGE models by explicitly taking into account random shocks and the intertemporal optimization of agents. OCT has been used in combination with dynamic CGE where the problem is converted into a stochastic control problem explaining the optimal path of alternative policies given different sources of uncertainties. As DSGE and OCT approaches are currently not incorporated in iMAP the two approaches are explained in more detail here than PE and CGE models.

2.3.1 Dynamic stochastic general equilibrium (DSGE) models

DSGE models belong to the general equilibrium class of models, which are based on an economic theory where market mechanisms create a balance between demand and supply on the different markets and the whole economy. As their name indicates, DSGE models are dynamic, and they are well suited to analyze inter-temporal economic problems. They are particularly relevant for the modelling of dynamic economic behaviour because they focus on *the time path* of the variables and situations where expectations of the future, and the uncertainty surrounding them, affect current decisions.

Recent modelling literature shows that DSGE models can be fruitfully applied to the analysis of numerous economic phenomena (e.g. Smets and Wouters, 2003; Ghironi and Melitz, 2005; Consolo and Hertweck, 2008; Bukowski and Kowal, 2010; Christiano et. al., 2010; Iacoviello and Stefano, 2010; Faccini et. al., 2011; Holden, 2011). DSGEs have been effectively utilized as a standard tool in various fields of economics linking into their structure the economic growth theory (e.g. semi-endogenous growth mechanism, R&D impact on technological change on economy wide and at the sectoral level, human capital role in economic growth, etc.), labour market economics (e.g. endogenous unemployment in search and match, real and nominal wedge frictions, costly inter-sectoral labour shifts, etc.), game and contract theory (e.g. market frictions such as incomplete and asymmetric information, cooperative and non-cooperative games, adjustment and savings, etc.), fiscal theory (e.g. optimal taxation problems), monetary and capital market theory (e.g. endogenous monetary policy, price rigidities, etc.), and international trade theory (e.g. transport cost, exchange rates, expansion of varieties, etc.). In practice, any branch of the contemporary micro- and macroeconomic theory can provide a useful input for the DSGE modeller (Bukowski, 2012).

DSGE models are *fully* dynamic, which means that economic agents take into consideration future consequences of their decisions and macroeconomic shocks. In particular, in contrast to static or recursively dynamic CGE models, investment and saving decisions are mutually interconnected as well as endogenously dependent on the expected future behaviour of the economy and in particular on an expected value of the modelled variables (e.g. interest rates).

DSGE models directly incorporate uncertainty and imperfect foresight into the modelling framework enabling modellers to flexibly adapt the specification of the stochastic processes into the model code, as well as consider the uncertain information sets that are taken into account by economic agents in their decision problems. Those choices are crucial for the dynamic properties of the model not only in the short and medium but also in the long run.

Because of their stochastic nature, DSGE models do not have fixed parameters as such. In principle, any parameter of the model can be shocked and the dynamic consequence of such - permanent or temporary- disturbances can be analysed. In particular, the incorporation of variable and time dependent elasticities of substitution or returns to scale and the analysis of their consequences is straightforward.

DSGE models can easily accommodate all information contained in a typical I-O matrix or SAM. As they are much more flexible in their structure compared with CGEs, anything that can be modelled within the CGE framework can also be tracked within the DSGE methodology, but not the reverse.

According to Bukowski (2012), DSGE modelling can be suitable to model the agricultural sector, but he also stresses that for the application of DSGE modelling to the agricultural sector it is necessary to know the particularities of the sector (e.g. the cost structure and performance of the agricultural and food sectors) and be able to properly represent them in the form of optimization problems. For instance the consumer demand system can be expressed in the DSGE model exactly in the same way as it is normally done in the CGE model (e.g. in the form of nested CES functions) or some other demand functions belonging to other classes like translog or AIDS. Scope of disaggregation on the production side of the agriculture sector is limited only by the imagination of the modeller and the availability of the relevant data. In particular this concerns the feed and consumer demand as well as international and domestic trading patterns of final and intermediate agriculture products together with the interconnection of the agriculture to other sectors of the economy.

Following Bukowski (2012), one can relatively easily incorporate such phenomena like climate change, water scarcity or GHG emissions and abatement into the model structure (Bukowski and Kowal, 2010). Other possibilities include the modelling of endogenous technological adaptation of

economic agents to climate change or increasing water prices. Similarly substitution possibilities generated by high price levels can be tracked when, for example, the R&D sector is introduced into the model.

DSGE models have both lagged and forward-looking dynamics implying that economic agents take into account the future consequences of their decisions and macroeconomic shocks. The lagged dynamics arise mainly from lags in budget constraints, information and technical constraints. The forward-looking terms are expectations of future variables, both endogenous and exogenous. They arise from the intertemporal nature of the problem (i.e. the objective function). Wickens (2012b) points out that the best way to forecast these future variables might be by using rational expectations while doing otherwise would imply that mistakes are knowingly repeated. This also makes sense the longer the time horizon of the analysis.³ Investment and saving decisions are mutually interconnected and endogenously dependent on the expected future behaviour of the economy (i.e. interest rate).

The flexibility of DSGE models enables the modeller to choose a proper, traceable and application oriented system of equations that are based on sound micro- and macro-economic foundations whilst expressing the desired level of complexity of economic phenomena. For example, it is possible to adopt flexible functional forms (e.g. non-homothetic functions) in the production and household sectors. The time-dependent autonomous adjustment of particular sectors or economies is the result of many interdependent factors captured in the model (e.g. investment, prices, trade, labour rigidities). As indicated by Bukowski (2012), in this respect, data availability is probably much more constraining than researchers' innovative skill.

The solution to a DSGE model involves lagged dynamics but future expectations of exogenous variables only. This is because by design the solution eliminates the future expected values of all endogenous variables. As, by definition, we cannot explain exogenous variable changes as an output of the model solution, we need to find a way of forecasting their future values. Following Wickens (2012b), one possibility is to model the exogenous variables as pure time-series variables. This enables all the data to be represented as a model with just backward-looking dynamics, such as a vector autoregression (VAR)⁴. If the exogenous variables are policy variables, then we may wish to model them in other ways such as assuming we know their future values, or that they are generated by a policy rule. This would imply that these variables

³ It should be pointed out that this approach ignores path-dependency: Even if, with repeated decisions, mistakes are corrected, this does not necessarily imply a return to the same trajectory without the mistake.

⁴ VAR is used to capture the linear interdependencies among multiple time series, generalising the univariate autoregression by allowing for more than one evolving variable.

become endogenous and determined by the policy rule. Yet, there are two important differences between a DSGE model and a pure time series representation of the variables: i) Where there are exogenous variables which are expected to change in the future, the endogenous variables in a DSGE model will change immediately and not wait until the change takes place, as would happen in a pure backward-looking time series model; ii) the solution to a DSGE model imposes coefficient restrictions on its backward-looking time series representation whereas a VAR does not. In other words, a DSGE model can be thought of as a restricted VAR (Wickens, 2012b). Only if the restrictions are correct does the DSGE model offer an improvement over a pure time series model. However, the number of restrictions in large scale models, such as those normally encountered in agricultural applications, may become intractable and therefore the superiority of DSGE over standard VARs may become dubious.

According to Wickens (2012b), over a long time horizon the dynamics of a DSGE model (both backward and forward) may become much less important and possibly even redundant. Only the long-run solution may be relevant. If this is the case then one can go straight to the long-run solution and ignore the short-run solution. Alternatively, it would be possible to define the time period of analysis (time-intervals) as sufficiently long that the short-run solution would still be relevant. The long-term dynamics in DSGE modelling is however relevant if time paths are to be analysed.⁵

In macroeconomics the GE feature of DSGE models is important in order to analyse economy-wide repercussions. Nonetheless, it is also possible to use the technology of DSGE models in a PE context. This is done in macroeconomics when the decisions of individual economic agents like households, firms and government are modelled separately. The only relevant issue is whether the decision of an agent is intertemporal. This would apply to agricultural agents too. DSGE models will be relevant for supply-side decisions, especially where they involve long time lags such as in tree crops, animal husbandry and capital decisions (Wickens, 2012b).

One can draw a distinction between DGE and DSGE modelling. DSGE directly incorporates uncertainty so that modellers can select the stochastic process and information set relevant to address the economic decision problem at hand. If random exogenous variables are involved in the problem then DSGE models should be used. In effect, this implies that one should use dynamic stochastic programming methods and not Lagrange multipliers of dynamic programming. In practice, the two become the same if one uses certainty

⁵ However, it has to be kept in mind that these time paths are again conditional on the perfect foresight assumption, i.e. path dependency can matter because even if mistakes are corrected with repeated decisions, this does not necessarily imply a return to the same trajectory without the mistake.

equivalence to evaluate the expectations of non-linear functions of random variables. DSGE analysis uses dynamic (stochastic) programming which is almost the same as those used in optimal control theory (OCT).

Bringing evidence to bear on DSGE models is still a matter of some controversy. In macroeconomics, Bayesian methods are used increasingly in order to confine the parameters to preferred values and avoid allowing them to take what might be judged as implausible values obtained by using classical econometric estimation. Unfortunately, the more successful Bayesian methods are in constraining the estimates, the more questionable the model is. Calibration is, of course, an extreme version of Bayesianism. One solution is to simulate data from a Bayesian estimated model and then use this to estimate a pure time series representation of the model. These estimates of the time series model can then be compared with those based on the original data. The comparison may be made through the impulse response functions and long-run solutions of the two sets of data. If the two differ substantially then the DSGE model must be suspect.

Solving a DSGE model requires several steps. After setting up of the economic DSGE model the first order equilibrium conditions (FOC) are derived. Together with the structural equations, these FOC build a system of non-linear stochastic difference equations. DSGE can be solved as a first order linear approximation around a steady state using perturbation methods. Model parameters can be expressed as time dependent and the stochastic processes (i.e. autocorrelation of shocks, their mean and variance) can be reflected in the matrices of the model parameters allowing the analysis of the evolution of the probability distribution of model forecasts from period to period. In addition Bukowski (2012) underlined the flexibility of the Kalman filter in DSGE for impact evaluation and economic forecasting. By filtering the relevant variables it is possible to compute a smoothed conditional forecast based on the full information set. This technique allows to simultaneously checking the impact on the economy of several parallel economic changes (e.g. changes in taxation or government spending, shifts in economic growth trend or consumption demand abroad, as well as shifts in household preferences).

2.3.2 Optimal control theory (OCT)

This section explains the rationale for using OCT in a GE framework following Krasovskii (2012). Conventional CGE models typically assume that an economy is in the non-stochastic steady state (a standard interpretation of the base year data set) and apply the usual static calibration procedure even if the base year (calibration year) represents a temporary stage on the path eventually converging to a stationary state (or steady state) or is far away from the steady state (the latter is by far the more realistic situation). Clearly, because of their standard static nature they are not able to provide a meaningful long-

term forecast, especially for fast developing or non-stationary economies. In order to address this issue, dynamic CGE and DSGE assume that the economy can be in the neighbourhood of the steady state (e.g. deviation from a steady state could be due to random exogenous shocks or uncertainty) or is in a non-steady state situation. Though this is the more realistic interpretation of a base year's data set, calibration of these types of models requires the assumption that the basic data are consistent with the intertemporal equations of the model.

In situations where a random shock shifts the system away from the steady state, the optimization problem is concerned with the question on how to move the system back to the equilibrium. A survey by Kendrick (2002) provides an extensive historical review on how stochastic OC has been applied to such modelling.

The solution to OCT models gives optimal policies that lead the economy to the steady state from a given initial position along the optimal path. Similar to the DSGE approach, one can construct sub-optimal nonlinear stabilizers, which still keep the system close to the optimal path. The OC model can be run for various initial data: calibrated parameters from the data are used to define the level of the steady state and to determine behaviour of the optimal synthetic trajectories of growth. The ability to construct optimal trajectories starting from various initial positions provides a possibility to compare the modelling output with real data and to forecast. One can compare the resulting optimal trajectories with the historical data. This gives an opportunity to verify the model and to construct credible scenarios for future development which than could be also compared with real statistics available. Feedback rules can be implemented in the model to capture exogenous shocks and uncertainty. In this framework state dynamics are provided by deviations from the steady state and feedback control rules are applied to the linearized system around the baseline. Optimal stabilization policy causes the system to revert to equilibrium (Kendrick, 2002). In a system with uncertainty and noise, the Kalman filter can be successfully utilized as discussed above for DSGE models.

Until recently, OCT was mainly applied to aggregated economic models (e.g. the Solow-Swan model by Shell (1973)). In the long-term the system is then expected to converge to the steady state along an optimal path. However, the challenging aspect is to define the synthetic optimal trajectory that solves the optimization problem for a solution in an arbitrary initial position (Krasovskii, 2012).

OC allows defining a domain of states that can be attained by the system at any point in time (i.e. feasible states). In addition, investigating the viability helps in checking whether the system is able to reach certain objectives and analysing the feasibility of various long-term targets. However the

investigation of the attainable domain and their viability is still fairly complex and its application is currently limited to problems with low dimensions.

According to Krasovskii (2012), to improve performance of various types of models for simulation of policy impacts in longer time horizons, the short-, medium-term results of dynamic CGE (DCGE) or DSGE models can be aggregated into factors assumed to be exogenous in the control problem. The control problem would then generate long-term forecasts for its endogenous factors providing the trajectory bringing to the new steady state. In addition the OC solution would dynamically determine the equilibrium in the neighbourhood of the short- and medium-term solution of the DCGE or DSGE model. So, according to Krasovskii (2012), OC can be combined with DCGE or DSGE models to simulate sector specific policy for long-term impact analysis.

On the other hand, Wickens (2012b) has emphasized the apparent limitations of OC. The main limitation resides in the fact that feedbacks are inserted through a control rule from the state vector containing all the variables in the model and their lags, which can be very long in MCMR models (i.e. many thousands of variables).

3 Major methodological issues for long-term analyses

In the long term⁶, the real world economy can change substantially, for example natural resources once abundant might become depleted in a way that constrains traditional economic activity. Labour supply may diminish following negative demographic trends, but it can also rise if the participation rates of groups marginally attached to the labour market grow. Structural unemployment may rise or fall in response to technological and institutional shocks. Some sectors may shrink, whereas others will grow as the permanent shifts in consumer demand occur. Innovations will stimulate economic productivity but, at the same time, they should impact the variety of products available on the market and generate new substitution possibilities for private consumption and investment. Furthermore, the role of government is likely to evolve with respect to its size, policy profile and instruments applied (cf. Bukowski, 2012).

In the course of the project underlying this report, a wide range of model requirements for projections and analysis of long term impacts of alternative policy scenarios has been discussed. The following issues have been finally selected as major methodological issues that have to be tackled when simulating long-term effects of policies in the agri-food sector:

1. Representation of main long-term drivers:
 - a) Consumption patterns;
 - b) Technological change, and
 - c) Resource constraints.
2. Modelling of structural elements:
 - a) Representation of demand and supply based on sound micro- and macroeconomic foundations;
 - b) Specification of production costs and competition between economic actors;
 - c) Inter-sectoral and regional factor mobility;
 - d) Representation of EU trade partners, agricultural and trade policies and major trade developments, and
 - e) Structural change in a global agriculture.

⁶ It needs to be emphasized that the notion of “the long term” used throughout this report can differ from the typical one used in economics (‘modelling scale’). The long term here refers to a far-distant ‘physical’ future time period that is selected to be 2050 for the purpose of this project (‘real time scale’). This differs from the undated concept of the long term used in economics, which refers to the time necessary for policy to have all adjustments being completed.

3. Technical features:

- a) Incorporation of dynamics;
- b) Explicit modelling of stochastic dimension and imperfect foresight;
- c) Incorporation of variable and time dependent parameters, variable return to scale, non-homothetic functions, time-dependent autonomous adjustments and new substitution possibilities, and
- d) Use of forecasting errors and checks for forecasting stability.

Reflecting all these phenomena in a framework and using it successfully to assess public policy impacts in the long term is certainly a challenge. Several modelling tools are in principle available to address some of the issues mentioned above, with PE and CGE models being among the most popular ones. The selected major methodological issues for long-term analyses are further outlined in the following subsections, and where possible reference is made to how they are currently tackled in PE and CGE models.⁷

3.1 Representation of main long-term drivers

This section highlights the importance of adequately representing consumption patterns, technological development and natural resource constraints as main long-term drivers in the modelling approaches.

3.1.1 Consumption patterns

It is generally held that shifts in consumption patterns will be key drivers for future food demand and therefore agriculture. However, it seems very challenging to estimate food consumption paths and their shifts in the long-term. Some of these changes in consumption patterns are related to income growth and should be incorporated in the specification of the demand system, either through appropriate functional forms (non-linear Engel curves) or through shifts in the demand system.

Apart from these endogenous shifts triggered by population and income growth there will be shifts that are more difficult to explain and predict. In many industrialised countries empirical analyses have identified a shift in meat consumption towards poultry over time that goes beyond income or price effects. Diets in developing countries are changing in the course of urbanisation, often in favour of wheat as opposed to other cereals and in favour of meat consumption⁸. Sustainability is also a key trend that changes preferences from the past. Not only price matters but also the way they have

⁷ The use of OCT and DSGE models to address the selected methodological issues is specifically discussed in the context of recommendations in chapter 4.

⁸ If diets in India changed over time towards more meat consumption this would have tremendous implications for global food markets considering the size of this country. Shifts in consumption patterns away from meat may be even a promising strategy to reduce GHG emissions and could be pursued by policies (Witzke, 2012).

been produced and the impact on environment and social issues. New sustainability criteria will also change more and more the consumption behaviour of humans to more sustainable products (e.g. less meat consumption).

3.1.2 Technological change

Advances in the state of technology are generally expected to be one of the key drivers for long-term developments in agriculture. This relates to total factor productivity, but also feasible partial productivities like crop yields or feed conversion efficiencies. Predicting technological change is almost impossible (Wickens, 2012b) and it is still largely a black box in economics. Economics is not very successful in explaining the Solow residual from an empirical and modelling perspective. There is some evidence of links between R&D and productivity growth but standard errors are large. Knowledge spillovers are crucial but difficult to measure. The new growth theories address endogenous technological change within theoretical frameworks but empirical applications are lagging behind. Although some theories, e.g. price induced technological change are more influential than others their explanatory power is nevertheless limited. Indeed, one of the biggest problems with regard to the future is the dimension of technological change over time and between sectors, between factors (e.g. factor biased technological change) and countries. Another key problem with regard to projecting technological change is the introduction of new technologies such as the rise of information and communication technology (ICT). ICT affected and changed almost every relationship within the economy in the last part of the 20th century.

Estimation of technological change on the basis of past developments may not be very promising as new categories of production possibilities emerge. For example, conventional fossil resources have proven to be limited (or their exploitation very costly, including costs of environmental damages) so in future they will likely be more and more replaced by renewable sources. Biomass is one of these renewable sources. This creates links between agricultural and fossil energy based industries (energy, materials, chemicals) which changes the characteristics of the agro-food complex and leads to creation of many new industries. Given the size of the energy market the impact can be enormous. The future techniques for the bioeconomy cannot be therefore deducted from the past, although a change of relative price ratios helps to deduce further developments in this direction. The expected emergence of bio refineries within the bioeconomy will also change agricultural and energy-related markets and their interrelatedness. Oil price will be key determinant of these developments and oil price is very hard to predict and shows enormous fluctuations. Therefore, speed and level of transformation to a bioeconomy is rather uncertain. The current economy created many societal

challenges such as loss of biodiversity, food security problems and climate change. Different technological change trajectories and preference shifts will follow so new perspectives are necessary (e.g. deviation from past trends) to address these challenges.

Other examples are technical changes stimulated or counteracted by policy. The social acceptance of some key technologies such as genetic modification (GM) of plants and animals has major implications with regard to competitiveness of some regions and fertiliser/pesticide use and productivity (i.e. this might change relations from the past). EU policies (and consumer preferences) are currently opposing a widespread use of GMOs in EU agriculture that might boost productivity. Other important aspects are what would be the consequences of prohibiting certain crop chemicals in the EU as well as antibiotics in animal productions and how to reduce nitrogen emissions through 'low-nitrogen feeding' eliminating the excess supply of protein to animals. New sustainability criteria from the Renewable Energy Directive (RED) (2009/28/EC) and the United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (REDD) are changing the relation between for example, land use (REDD and RED criteria), fertilisers on the one hand and production growth on the other. This is crucial for emissions and production patterns.

Due to their potentially highly disaggregated nature, PE models may be linked to include technical information from the natural sciences. This technical expertise can determine certain parameters in the PE model or define boundary conditions to comply with technical limits. This link is straightforward establishing especially if the PE model is of the programming type (e.g. GLOBALBIOMASS Optimization Model, GLOBIOM⁹) as biophysical models are used then to define the technology set. In GLOBIOM cost is approximated with engineering data for crop technologies differentiated according to altitude, soil, form of rotation and irrigation systems. Technological change is relatively simple and can be decomposed in input related and input neutral. Input related technological change is endogenous and depends of fertilizer levels and tillage. Input neutral technological change is exogenous and depends on exogenous yield growth due to improved seeds. Two types of technology are considered: extensive and intensive. However, this approach is also conceivable for other PE models (e.g. CAPRI) where technically feasible maximum yields and their evolution over time and space is valuable inputs to specify shifters for crop yields. However, such communication is not without problems.

⁹ GLOBIOM is a global recursively dynamic partial equilibrium model integrating the agricultural, bioenergy and forestry sectors with the aim to give policy advice on global issue concerning land use competition between the major land-based production sectors. GLOBIOM is developed and maintained at the International Institute for Applied System Analysis (IIASA), Laxenburg, Austria.

Crop scientists may consider very large yields feasible, provided that fertiliser, water and management efforts are in unlimited supply. This may be a reasonable approach under experimental conditions but some acknowledgement of the 'yield gap' (i.e. the gap between average and potential yields) would need to be made. Furthermore, biophysical models are typically not calibrated to reproduce observed crop yields over time in certain regions. Transferring models designed for very small plots to larger simulation units may involve a serious loss in empirical content. Similar communication is conceivable with animal nutrition experts. Many PE models already include feed ratios and gains in feed efficiency that can be cross checked by technical experts provided that sufficient disaggregation is available in the model. The limitation is mostly the time needed to compile such information in collaboration with scientists and the availability of technical and economic data at the same level. Nonetheless, disaggregated modelling permits at least communication between technical experts and economic modellers, communication that becomes the more difficult, the more aggregated products are (e.g. cereals vs. wheat).

3.1.3 Natural resource constraints

There are widespread concerns that natural resource constraints (climate, soils, water) are increasingly limiting agricultural productivity. Impacts of climate change on crop yields (if they are known in technical terms) can be implemented easily in all equilibrium models that provide for exogenous yield shifters. This will hold for most equilibrium models that distinguish crop yields and areas explicitly. Even in models without such a distinction it is possible to shift supply functions according to some estimated climate impacts. Of course, a higher degree of disaggregation, both in terms of crop mix and technology variants that may be typical in programming-type models would help to appropriately reflect these challenges. This directly relates to water, a key resource in agriculture. It appears that until now the most detailed coverage of water scarcity has been achieved in the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) from the International Food Policy Research Institute (IFPRI), at least when limiting the consideration to those with global coverage (cf. Rosegrant et al., 2008; IFPRI, 2013).

The most important natural resource for agriculture is land in suitable condition. As a consequence this is covered in most MCMR models in one form or another. A key problem is heterogeneity of land qualities over space that results in a decline in average yields or an increase in average marginal cost if agricultural land expands at the expense of former non-agricultural uses (extensification effect). The relative merits of PE and GE approaches are somewhat unclear. On the one hand regional disaggregation may help to explicitly acknowledge the heterogeneity of natural conditions that would be

expressed by some parameter in more aggregate modelling. On the other hand it is highly desirable to cover all land uses competing with agriculture in one system, as would be the case in CGE models. Completeness in coverage would, for example, permit to capture the increase in urban areas (presumably linked to economic growth) and the reduced land availability for agriculture, forestry or other natural land. However there is a more practical aspect favouring total over partial land use coverage. Due to the wide divergences in databases on aggregate land uses it appears that the only data known with certainty are the total areas of countries. A complete area balance would act as a hard constraint to modelling, and hard constraints are quite scarce when considering the very long-term. This physical constraint on total area is in principle easier to implement in PE modelling because most CGE models covering land represent this as a nonlinear constraint for transformation among crops (typically of the constant elasticity of transformation (CET) form). However in a CGE framework it is also possible to remove the CET and introduce a land market as implemented in PEs. This approach, even though defensible from a theoretic point of view, does not include a physical balance as land is represented in quality corrected form only. However, agricultural PE models would have to make assumption or establish linkages to models for non-agricultural land use to achieve full area coverage.

Relevant policy scenarios for the long term should probably focus more on climate or environmental goods in general than on traditional agricultural topics, at least when focussing on EU policy. Some PE models may include such policy driven technology changes only in exogenous form as part of the scenario definition (e.g. CAPRI), others may endogenise this technology choice by offering several management options to the model that would determine the optimal mix according to some objective function (e.g. GLOBIOM). A key limitation of PE models for climate policies is that all sectors contribute to global emissions and balanced climate policies should try to minimise abatement costs across all sectors. Their completeness is clearly an advantage of CGE approaches to climate policy modelling (e.g. MIRAGE, MAGNET). The ENVISAGE model (Van der Mensbrugghe, 2010) is well suited for this analysis; it can be classified as an integrated assessment model, where changes in climate parameters, such as the temperature on productive activities, result from economic growth and its outcomes in terms of emission. The impact on the production of individual sectors, including agriculture, is therefore endogenous to the growth scenario.

3.2 Modelling of structural elements and changes

This section discusses the modelling of structural elements like changes in demand and supply, production costs, factor mobility and trade developments.

3.2.1 Representation of demand and supply based on sound micro- and macroeconomic foundations

Micro-foundations simplify the choice of functional form and parameter calibration (or estimation) in PE and GE models. Whereas some PE models largely neglect microeconomic constraints (FAPRI, AGLINK, IMPACT, FAO supply side) others adhere to it (CAPRI, FAO demand side). Regarding the long-term drivers of agricultural markets, static and dynamic MCMR models can (at least in theory) adequately represent the consumption patterns, including the contribution of economic factors to the evolution of consumption. Key demand drivers (e.g. population and income growth) are available and can be borrowed from official projections or other models. Predictions for population in the past have not been very accurate and they depend partly on economic factors and policies. More difficult to treat are preference shifts that can be eventually extrapolated or derived from expert knowledge. By definition, PE and GE models acknowledge the own and cross price effects as well as the income effects in their demand systems. One possible area of improvement for the representation of preference shifts lies in the functional form specified to capture household preferences. Most models adopt non flexible forms such as the Linear Expenditure System (LES) or the Constant Difference of Elasticity (CDE). While better than a simple Cobb Douglas or CES approach, they still suffer from constrained own and cross price elasticities. Recent trend is to introduce the so called AIDADS demand system; thus introducing endogenous Engel effects (e.g. GTAP, ENVISAGE, FAO demand side). This is a valuable improvement but it should be recognized that this system still severely constrains cross price effects. Other more flexible representations are possible, such as the Normalised Quadratic (see Gohin and Laborde, 2006) or using the latent separability concept (Gohin, 2005). These solutions are still regular and thus allow the specification of any consistent set of substitution and income elasticities.

The same issue exists on the supply side for the representation of technological possibilities and changes. The static and dynamic models can be improved in the same way to better capture substitution patterns between inputs and adequately represent the agricultural supply. The process of technological change is largely exogenous to the equilibrium models. Based on weak empirical evidence some models endogenize part of technological change by introducing price induced technical change or R&D investments explicitly. Although endogenous growth model may be appealing they are still not able to predict advances in technologies (e.g. C4 metabolism in cereals, new energy crops, future of aquaculture, reduction of CH₄ emissions from ruminants, etc.).

In both the demand and supply sides, the issue is in having the right projections for the evolution of exogenous parameters, such as the changes in the household preferences toward final goods (not motivated by prices and

income) and in the input productivities. Micro-econometric results can be useful to calibrate these evolutions, with some care to ensure that these results are relevant to the aggregation level desired. As regards the resource constraints, they are also captured and can be improved.

Behavioural functions strictly based on microeconomic theory are not without problems. Most importantly there are aggregation problems hidden under the surface when considering that supply and demand functions should represent aggregates of very heterogeneous populations of 'real' agents. These problems are mostly ignored or it is simply assumed that the respective aggregation conditions hold without evidence. The best argument in favour of representative agent modelling based on micro-theory is that it aims to improve the consistency and transparency of modelling. Some models try to reduce aggregation problems by considering several representative agents on the supply or demand sides. CAPRI, for example has regional sub-models as well as farm type models. Several CGE models disaggregate the representative household to address distributional issues.

As is the case with microeconomic theory, the introduction of any relevant technical constraints that can be specified may also contribute to improve the quality of long-term projections. It should be acknowledged that CGE models may benefit from other consistency relationships that are missing in the PE context: macroeconomic closure rules and the accounting identities of a SAM. These constraints are just as valuable as the constraints typically used by PE models for agriculture. However, it appears that PE modelling offers greater opportunities for constraints related to agriculture only.

3.2.2 Specification of production cost and competition between economic actors

New trade theories show the importance of imperfect competition with regard to welfare implications of trade policies. Most PE models only consider price formation in the most simplified form possible: perfect competition with exogenous margins. Alternative solutions are theoretically more convincing and in line with the scarce empirical evidence that has checked for imperfect competition. However, imperfect competition would also complicate the structure of a PE model. Among CGE models, the MIRAGE model specifies imperfect competition in downstream industries. Francois et al. (2005) specified various ways to include economies of scale and market imperfection within a CGE (GTAP) model at relatively low costs. In the standard MAGNET model perfect competition remains but there are several applications with imperfect competition that show the importance of imperfect markets in case of trade liberalisation (e.g. Francois et al., 2005). However, the empirical evidence to measure the degree of market imperfection is weak and the welfare results are very sensitive to these assumptions. In Francois et al.

(2005) gravity models were used to estimate the degree of market imperfection.

The role of market failure is addressed in Gohin (2012). Most models are developed assuming the absence of market failures, market power, contingency market, and risk. Gohin (2012) particularly focused on market failures that can be of different types, such as the existence of public goods, market power and missing Arrow Debreu contingent markets. Dynamic models are particularly relevant to analyse this last issue. One example is given by Femenia and Gohin (2012) who analyse the best implementation of policy reforms when economic agents suffer from informational issues. In other words, long-term contingent markets are absent forcing economic agents to make their own expectations of future prices. This issue is often overlooked in economic analysis of farm policies where the focus is on the long run, steady state impacts. Femenia and Gohin (2012) offer a determinist dynamic CGE analysis allowing agents to form adaptive versus perfect expectations. Using the forthcoming CAP reform scenario as a testing case, an abrupt versus a gradual implementation of this reform over the period 2014 to 2020 is simulated. Results show that if economic agents are able to perfectly anticipate the impacts of the reform, then delaying its implementation is never optimal. They start adjusting their production patterns once the reform is announced, so that the markets smoothly reach their steady states. On the other hand, if agents have imperfect knowledge of the full structure of the economy and then gradually learn from market developments, there are some cases where a gradual implementation of this reform is welfare-improving. By contrast an abrupt implementation generates initial losses due to significant adjustment costs. These initial losses are all the more important that agents, in particular farmers, strongly react to last price observations. Accordingly, it may be optimal to gradually implement reforms so that agents smoothly learn from market developments. More generally, this analysis shows an optimal policy design in an economy suffering from informational inefficiencies. Under this experiment, Femenia and Gohin (2012) show that static results are robust when facing limited shocks but they are not robust if we have strong assumptions on expectations. Introducing expectation errors in the form of adaptive expectation brings endogenous market fluctuations that remain limited in a CGE framework. Gohin (2012) suggests that when we face volatile environment it is more important to analyse different expectation schemes.

In addition, Gohin (2012) further highlights the importance of market imperfection. In an empirical application on foot and mouth disease in Brittany it is showed that welfare implications due to a supply shock and trade ban differ if market imperfection are included. Capital (i.e. cattle herd) represents the state variable in the model and capital can be changed at the end of the period through new investments (e.g. new calves). Initially rational

expectations are assumed and then market imperfections are introduced through an Euler equation on the labour market assuming involuntary unemployment and on the financial capital market assuming that some farmers and food processor may be credit constraints. The assumption is that there are investments that may be constrained by the fact that during last year economic crisis, negative profits may not allow to renew investments. When we introduce imperfection on the labour market and on the capital market and we introduce that food processors may be constrained when they want to renew their plants, the welfare decline is much higher than for the case without market imperfections. From the welfare effects a common mistake is to refer to the equivalent variations on consumer side without focusing on the value of capital stocks.

Example: Assessing the economic costs of a Foot and Mouth Disease outbreak on Brittany: Macro-economic imperfections greatly impact the aggregate economic cost of the disease and its distribution

Version of the model	Perfect factor markets	Constraint on investment	Constraint on wages	Both constraints
Annual Equivalent variation	-3.8	-0.5	-34.1	-88.3
Value of land	-2.9	-76.0	-3.8	-85.4
Value of physical capital	6.4	-127.7	-43.9	-367.5
Value of cattle herd	1.6	-69.5	1.8	-70.3
Value of foreign debt	273.8	265.8	435.4	226.3
Discounted welfare	-168.9	-264.7	-585.4	-1276.9

Source: Gohin (2012)

3.2.3 Inter-sectoral and regional factor mobility

Generally it is assumed that PE models cannot depict factor markets, presumably because factors are employed in several sectors which go beyond the perimeter of the PE model. However, this needs to be qualified as most PE models by now include at least land explicitly which is either constrained by some total agricultural area (Common Agricultural Policy SIMulation (CAPSIM), CAPRI solution before 2009) or which may be converted into some 'other land' that is often unspecified (FAPRI, ESIM, AGLINK).

A land category of potentially usable agricultural land is currently also part of the CAPRI model, whereas in the MAGNET model the land supply curve is based on biophysical information from the IMAGE model (Meijl, et al., 2006, Eickhout et al., 2009). Land of suitable quality may be thus considered as being supplied by some non-agricultural land owner, a solution that avoids explicit modelling of land demand from non-agricultural sectors and is applied both in CGE and in PE models. Note that full area coverage may equally rely on

some reduced form behavioural functions for non-agricultural areas if only an aggregate closure is desired.

By contrast, most PE models indeed largely neglect agricultural labour and capital (FAPRI, AGLINK, FAO). In microeconomic theory and empirical work based on profit functions, supply side behavioural equations should depend on factor prices or quantities. ESIM and IMPACT are indeed examples with explicit prices of labour and capital. In some PE models labour and capital are considered an aggregate primary factor (CAPSIM, CAPRI)¹⁰. Programming type models sometimes have labour or capital requirements with either a fixed or price dependent total supply.

The neglect of agricultural labour and capital in PE modelling is partly a consequence of data problems. The data requirements for a high quality indicator of labour and capital use in agriculture are considerably more demanding than for variable inputs, land use, animal herds, or outputs. The standard approach to the measurement of capital (perpetual inventory method) requires long time series of investment data which are difficult to obtain. Equally important are the data problems with an appropriate recording and aggregation of part time and full time family labour in agriculture. Even given high quality data on labour and capital, disaggregate modelling requires at least marginal coefficients (if not a full input allocation) to capture the effects of these primary factors on a number of activities (about 60 in the case of CAPRI). As these coefficients are less frequently estimated as price elasticities, empirical knowledge on them may be shaky. Further empirical econometric analyses would be useful to determine which effect of primary factors is important for a relevant number of activities.

In CGE models all factor markets are endogenous although perfect factor mobility prevails. Within the MAGNET model imperfect factor mobility is modelled between agricultural and non-agricultural sectors. The function is estimated and has together with the land supply curve a crucial impact on competitiveness, production and trade implications of exogenous and policy shocks as demonstrated in the Scenar2020 studies (Nowicki et al., 2007 and 2009).

3.2.4 Representation of EU trade partners, agricultural and trade policies and major trade developments

Most PE and CGE models suitable for long-term projections should be global in nature because global demand growth, in particular in developing countries will be a key driver for the future. However, the question is more open when it

¹⁰ The labour/capital aggregate may be considered a factor with a given price in CAPRI (in particular when iterating with regional CGEs) or it may be considered fixed and implicitly constraining the model result (Witzke, 2012).

comes to the appropriate regional breakdown of the world, to the trade policies of those regions and their bilateral trade flows. A very detailed regional breakdown allows addressing new questions (for example an environmental constraint on palm oil production in Malaysia and Indonesia) that could not be tackled with a more aggregate regional breakdown and have not been anticipated some years ago. Furthermore a rich regional breakdown facilitates the linkage to other models that typically have their own regional breakdown of the world. From this perspective a country level disaggregation is ideal, but evidently it also involves huge cost in terms of the information needs¹¹.

Related to the breakdown of regions is a breakdown of policies. Policy coverage may differ considerably between models. Some consider policy only to represent a parameter in a price transmission function; others have explicit tariffs, TRQs, domestic subsidies and so forth. It depends on the long-term scenarios investigated whether an implicit or an explicit representation of policies is required. Finally, the value of bilateral trade modelling should be reconsidered. It is clear that bilateral trade flows and trade policy instruments are a key ingredient of a modelling system designed to address WTO scenarios. For the very long-term it is less clear whether the additional equations that certainly increase the model complexity are worth the effort.

Some systems (CAPRI, GTAP) model bilateral trade based on the Armington assumption others rely on a Takayama-Judge approach (GLOBIOM), each with their own pros and cons. As far as the policy instruments are concerned, it should be recognized that great improvements have been made in recent years to improve the representation of trade policy instruments. The MacMaps detailed database developed at the Institute for Research on the International Economy (CEPII) offers a lot of information that can be aggregated to the model needs. Some improvements are underway, for example by the LEI with MAGNET, to represent domestic policies, including the two pillars of the CAP. More works are needed to better represent the production and market effects of these domestic instruments, such as the direct payments granted to farmers in the EU and in the US.

¹¹ The GTAP database, which contains 129 countries in the current Version 8, may be a good example, potentially limited to a model with much standardised entries in the database. It appears that no PE model has achieved a similar degree of standardisation to be able to obtain a regionally aggregated version with relatively moderate efforts. The GTAP achievement is due to an institutional innovation in which many core members pay in cash and in kind to create and maintain a 'public' dataset at the GTAP centre. The dataset is the real value and based on this dataset many models are developed and entry barriers to engage in quantitative CGE modelling are lowered drastically. However, the GTAP database is only a starting point and serious policy analyses require data improvements in the parts that are most crucial for the policy question at hand.

3.2.5 Structural change in a global agriculture

Structure in economics can be defined as ‘the different arrangements of productive activity in the economy and different distributions of productive factors among various sectors of the economy, various occupations, geographic regions, types of product, etc.’ (Silva and Teixeira, 2008, p.275). Structural change usually has a long-term meaning looking at shifts in the sectoral composition of economic systems. Aspects of interest for the long term are how the relative importance of economic sectors is changing over time and how the distribution of economic activities (e.g. urbanization) as well as the institutional environment is changing. According to Silva and Teixeira (2008, p.273), economic dynamics ‘can be studied by focusing on a relatively small number of groups or activities that comprise the economic system, and thus form the economic structure’. In the economic literature the drivers of structural change have been identified by reference to different economic growth theories. From Schumpeter’s theory, the main driver of structural change is innovation that is disseminated through improvements and imitation (i.e. diffusion) (Schumpeter, 1939). Modern economic growth would be impossible to attain without structural change for Kuznets (1971:348). Similarly, continuous structural transformation and change are linked to economic growth (Pasinetti, 1984). In the neoclassical school, structural change is viewed as a result of market development rather than a requirement for economic growth. The current fragmentation of the value chain has decreased the interdependence of economic activities within domestic borders. Therefore, it seems more relevant to move from the classical view of a horizontal representation of the economic system to a more vertical approach. For example, Silva and Teixeira (2008:283) refer to a ‘unidirectional relationship and asymmetric dependence in the clustering process’. According to this view, where the economy is conceptualized by one-way relationships from upstream sectors to downstream sectors, structural change takes place by reallocating production factors from one activity to another activity. The ‘kaleidoscope comparative advantage’ of Bhagwati and Deheja (1994:24-26) emphasizes the variability of factors in defining the geographic location of the different parts of the value chain at different regional level (i.e. global, national, regional). This highlights the importance of considering movements towards activities with higher value added within an international value chain that goes beyond domestic industries.

Regarding the structural elements of agricultural markets and sectors, CGE models as compared to PE models include by definition all upstream and downstream sectors. Some versions of CGE models, like the MIRAGE model, introduce imperfect competition in downstream sectors. In MAGNET, the oil and fat processing sector is being disaggregated to distinguish the different vegetable oils and meals. Some work has also been done to distinguish the

retailing sectors that can have great impacts on the farm sector and markets (see for instance, Bradford and Gohin, 2006). Like most PE models, these CGE models are also built on the assumption of the existence of a representative economic agent in each sector. Again this assumption is made mainly due to data constraints. The main issue here is to obtain relevant economic information to represent these sectors and behaviours.

3.3 The technical dimension

This section discusses technical features like the incorporation of dynamics, stochastics and forecasting errors.

3.3.1 Incorporation of dynamics

Dynamic relationships in agriculture may be due to several factors. Agricultural production processes take time; for example, in the animal sector time is needed to first rear young animals before adult herds can be expanded. Adjustment costs in the form of learning costs are attached to any change in input use or output mix. Imperfect capital markets can slow down farm expansion. Some kinds of adjustment costs are compatible with a long-term comparative static solution, but others are not (Threadway, 1970). Dynamic relationships may therefore have effects on the form (or even existence) of a long-term equilibrium as well as being relevant for a simulation of a transition path to this equilibrium.

The theoretical case for dynamic behavioural equations is less clear on the demand side. Habit formation may suggest that long-term elasticities should be larger than medium-term elasticities. On the other hand it is conceivable that short-term responses are stronger than long-term responses (consumers may be willing to substitute sausage for cheese after an increase in the cheese price for a number of weeks but after a while they may accept that cheese has become more expensive and increase cheese consumption again). Hence it is mostly an empirical question whether long-term and short-term price elasticities of food demand should differ. A time-dependent change in consumption pattern, including a change of preferences between work and leisure, could help the modelling of structural change on the demand side. Moreover, a dynamic approach on the demand side would also be necessary if issues concerning a trade-off between savings and consumption (e.g. consumption smoothing theory or live cycle hypothesis) had to be considered.

However, if dynamics could be included in models without cost it would be evident therefore that all our models should be dynamic. Unfortunately, additional complexity through the inclusion of dynamic elements to PE or CGE models has a cost in terms of information requirements, computing time, and ease of model interpretation and analysis.

Formally, two methods are available to incorporate dynamics into equilibrium frameworks: recursive dynamic and fully dynamic. In the recursive dynamic model, only myopic or adaptive-type of agent expectations are allowed. Myopic expectations assume that there is no change in decision rules from period to period. On the other hand, adaptive expectations mechanisms allow agents to take into account only the past in their optimizing problems. Sequential solutions can be easily obtained. These models can also be easily solved for the long-term. Fully dynamic models also have forward-looking behaviour and inter-temporal dynamics that require advanced solution algorithms. In fully dynamic models (e.g. DSGE), all state variables can change from period to period following some adjustment rules based on the decision and expectation of economic agents. Investment is endogenous and conditional on expected rates of return or on the future behaviour of the economy (Bukowski, 2012). In the fully dynamic framework (e.g. DSGE models), agents are no longer restricted to one single period for the optimization but rely on an inter-temporal framework allowing substitution between savings and consumption or between labour and leisure. This type of model cannot be solved sequentially since from the outset economic agents compute all equilibrium prices for the following years. Hence, if the regional and sectoral dimension of the equilibrium model is very large, then it is quite unrealistic to solve them for 40 years ahead.

Some forms of dynamics are typically included in PE models that rely on econometric estimation of some of their parameters (FAPRI, AGLINK, AGMEMOD). It seems that parameter estimation (based on annual data) can benefit from lags in the equations. However, this does not necessarily mean that in these PE models the final simulation model is dynamic as well. By contrast, PE models that rely on a calibration approach (CAPRI, FAO supply side) often neglect all forms of dynamics.

In the four CGE models MIRAGE, ENVISAGE, MAGNET and ID3, the dynamics are of the recursive type. In the first three (MIRAGE, ENVISAGE and MAGNET), the dynamics are quite simple because most of the dynamics occurs outside the model proper, i.e. in between solutions. The main exception is the capital accumulation function. In the MIRAGE model, regional savings are also assumed to be fixed proportions of regional incomes for each simulated year. These savings are allocated annually to investment in different sectors and different regions according to present capital returns. MIRAGE assumes that end-of-the-year simulated capital returns will prevail in the next period (i.e. a naïve expectation). ENVISAGE basically inherits from the former LINKAGE and MAGNET CGE models where agents are assumed to be myopic and to base their decisions on static expectations about prices. More precisely, regional savings represent fixed shares of regional incomes. Regional investment is set residually to balance domestic plus foreign savings, the latter being

determined from an exogenous current account surplus or deficit. Jorgenson and Goettle (2012) develop a fully dynamic CGE for economic, environmental and energy policies for the long term¹². Forward-looking behaviour is introduced on both the supply and demand sides together with lags on investments, capital stock and capital services. The evolution of economic growth depends on energy, environmental policies and on their impacts on intermediate-run trends. The approach of Jorgenson and Goettle (2012) puts more emphasis on econometric estimation than is normally applied in CGEs. In addition, there is heavy emphasis on perfect foresight inter-temporal optimization.

Thus, most CGEs implicitly specify potentially restrictive expectation schemes for investment and saving decisions. They assume static (myopic) price/return expectations and thus do not recognize the effects of policy shocks on these dynamic decisions. Moreover, they do not recognize the lag between production decisions and output marketing and thus also neglect the expectations associated with this dynamic as well. On the contrary, the ID3 CGE model (Boussard et al., 2006) introduces this dynamic dimension for agricultural sectors. This requires the introduction of output price expectations in these sectors and the possibility of expectation errors. These expectations are based on past observations (Nerlove expectations with the naïve case as one extreme possibility). This assumption allows the authors to solve their model sequentially like other recursive dynamic CGE models. On the other hand, this assumption prevents economic agents from modifying their behaviour if some policies are announced before being implemented. In other words, it assumes that economic agents, including agricultural producers, are always surprised by policy reforms.

3.3.2 Explicit modelling of stochastic dimensions and imperfect foresight

The stochastic dimension has different sub-dimensions that also seem to differ in importance for long-term modelling. Parameter uncertainty and input uncertainty imply that model projections should be considered as point estimates drawn from a whole distribution of model outcomes. Policy makers would often include these uncertainties in their reasoning about alternatives. The increased frequency of extreme events from weather shocks may be a

¹² The IGEM model described in Jorgenson and Goettle (2012) contains 35 industries and has been extensively used for examining energy and environmental issues where the effects on the U.S. economy of meeting greenhouse targets has been simulated over the period 2012 to 2060. The production function assumes constant returns to scale and relies on a translog unit-cost function econometrically estimated. Households live forever, have perfect foresight and can choose paths for consumption, saving and leisure maximizing an intertemporal utility function (e.g. consumption and leisure).

particularly relevant example for long-term climate issues¹³. However, it may also be questioned whether policy makers are able to express their objective function or specify exact distributional assumptions.

Most PE and CGE models are deterministic and only address specific uncertainties through sensitivity analysis. However, less sophisticated forms of sensitivity analysis (i.e. this does not apply to systematic sensitivity analysis, using e.g. Gaussian quadrature approach) can focus on a very limited number of specific sources of uncertainty only. In addition, sensitivity analysis does not allow the analysis the reactions of economic agents and their attitude to risk. This may easily become unsatisfactory if many sources of uncertainty are considered simultaneously since the number of sensitivity analyses to be performed would need to increase dramatically.

At present, there are three large scale agro-economic PE modelling systems that have a stochastic functionality: FAPRI (FAPRI-UMC), AGLINK-COSIMO (OECD-FAO), and ESIM (Hohenheim University-IPTS).¹⁴ All three models are able to analyse uncertainty in crop yields. To represent the stochastic variability of yield, the three models use deviations from trend as estimated from annual data on historical crop yields (depending on the commodity and the coverage of the particular model, de-trending is performed at different levels of aggregation). To generate the stochastic components, a multivariate distribution is assumed in the models. In ESIM and AGLINK-COSIMO, a multivariate normal distribution of the stochastic error components is assumed and is parameterised using the variances and covariances of the historical yield deviations. In FAPRI, an empirical multivariate distribution is fitted to the stochastic error components. Various techniques are used to make a number of random draws of correlated crop yields from these multivariate techniques: Gaussian Quadrature (ESIM), Latin Hypercube (FAPRI) and Monte Carlo (AGLINK-COSIMO)). The draws are then fed into the model, and the model is simulated the required number of times, each time with a different set of stochastic yields. FAPRI also performs stochastic analysis with regard to exogenous energy and cost variables, domestic demand and domestic stockholding, and trade in the rest of the world. Having derived the joint distribution of these variables, FAPRI makes joint draws from this multivariate distribution of exogenous values for prices of crude oil and natural gas, fuel

¹³ In GLOBIOM at IIASA, crop yield variability is estimated from historical data on yields from FAOSTAT for the period 1961-2006. This implies the construction of a covariance matrix with yield distributions for about 100 crops per region. This allows incorporating in the system price volatility through yields. The model minimizes the maximum expected loss in the tail of the probability density function. In other words, the objective function minimizes risk over the long-term. The model also generates global stocks considering rules of intervention, size of the stock and the optimal stock given a certain price.

¹⁴ This paragraph draws on Burrell and Nii-Naate (2013). Their report documents the stochastic functionality of the three modelling systems, giving a detailed description on the methodology and a range of applications to illustrate it.

costs, seed costs and labour costs. On the demand side, FAPRI has three groups of stochastic variables (regarding domestic demand, stocks and foreign demand). AGLINK-COSIMO is able to also perform macroeconomic stochastic analysis (a detailed description of the methodology used in the AGLINK-COSIMO model is given in Burrell and Nii-Naate, 2013).

It has to be kept in mind that uncertainty may not only influence yield variability but also the behaviour of economic agents (e.g. their risk attitudes and expectation formation). Thus, the current applications of stochastic terms in PEs do not necessarily tackle the corresponding attitude of economic agents towards risk. For example, these models can introduce the fact that agricultural yields are random but they fail to model the decision of farmers to purchase crop insurance or to rely on future markets. This can be considered a shortcoming of the current applications, since agricultural policies seem to put more and more emphasis on stochastic elements like weather and yield variability (for example by subsidising crop insurance fees).

3.3.3 Incorporation of variable and time-dependent parameters, variable returns to scale, non-homothetic functions, time-dependent autonomous adjustments and new substitution possibilities

In general, it is difficult to model time-varying parameters unless one has a long historical time series when structural change is highly likely. Predicting future changes is very hard especially where new products may appear. In addition structural changes that occurred in the past will not necessarily be repeated or extended in the future. According to some economists (e.g. Wickens, 2012b) establishing how elasticities are affected by income may be the most that can be done in this context. The ENVISAGE model and its AIDADS demand system go in this direction. If the emphasis is on generic things like calorie intake and roughage rather than specific commodities this might be easier. Time-dependent autonomous adjustments are generally a result of the model itself (Wickens, 2012b). Economies of scale and logistic information in the supply chain are becoming very important especially when tackling the bioenergy sector. In GLOBIOM, for example, the transportation infrastructure determines a cost map for the supply chain.

3.3.4 Use of forecasting errors and checks for forecasting stability

The use of forecasting errors and checks for forecasting stability might seem appealing when it comes to validating modelling results. However, it has to be kept in mind that the models used in iMAP are not forecasting models. A check for forecasting performance for long-term projections seems to ask for the impossible. Such models should not be judged on its forecasting performance as PE and CGE models are meant to produce medium-term projections

conditional on an information set of exogenous variables. Most PE and CGE models are synthetic in their nature, making an explicit and formal treatment of forecasting errors based on ex-post data difficult. Therefore, the use of past forecasting errors does not seem to be a coherent and relevant choice and it might be better to test a model in-sample. By contrast a relevant check could be to perform an ex post projection to say 2010, using the information available in 1970. Apart from the fact those current databases may not extend sufficiently into the past for estimation based on prior 1970 data only, there are several other reasons why such a check is likely to be inconclusive. Parameters and exogenous inputs will be strongly influenced by past policy reforms, by the economic transition in Middle and Eastern Europe, by the emergence of biofuels and the take-off of China and other emerging economies. Some of these developments may have been anticipated in 1970 but most will not. The key question is whether a model based projection would have increased the quality of projections over alternative approaches, say qualitative reasoning, pure time trends (e.g. based on data for 1950-70) or other methods. However, this will be nearly impossible to check in advance.

4 Making the right choice: discussion and recommendations

The increasing interest in detailed analysis of long-term impacts of policies and programmes affecting the agricultural and food sector indicates a role for IPTS to assess the requirements and challenges entailed with long-term simulations. Given the current modelling capabilities in iMAP, the focus is on PE and CGE modelling approaches. Considering the selected major methodological issues for long-term analyses outlined in chapter 3, several crucial aspects need to be addressed, namely the choice of a PE or CGE approach, the modelling of structural elements, the incorporation of technical features and the applicability of other methodologies and theories (i.e. DSGE and/or OCT). These crucial aspects are discussed in this section, and specific examples and recommendations are provided.

4.1 On the PE or CGE choice

This section explores whether a PE or CGE approach should be preferred for analysing long-term policy impacts. According to some experts (e.g. Dixon, 2012), the two approaches should be combined. PE models can be used to gather and process specialist information on particular parts of the economy. Results from PE analysis can then be passed to a GE model to work out economy-wide implications. It could be also the case that results from CGE analysis can be passed to a PE model to work out the sectoral implications or in order to disaggregate results further. The suggested two-level approach is also currently followed by the Global Perspective Studies team of FAO combining an integrated assessment GE model of the global economy (ENVISAGE) with a new global PE model (Conforti, 2012). The original idea at FAO was to use a PE¹⁵ for certain types of question and GE to answer more complex questions and align the two with medium-term projections (OECD-FAO) and ENVISAGE. Demand and supply drivers require both disaggregation and technical expertise regardless of the methodological approach selected. CGE models are typically better equipped when it comes to analysing climate change, the bio-based economy and factor markets or in low-income countries or rural regions where there are still important feedback effects from agriculture to the rest of the economy (Witzke, 2012). However, agricultural PE models for climate policies can be also linked to an energy model (e.g. PRIMES) that would add the information on marginal abatement costs. Alternatively it might be also possible to treat either the 'carbon price' or the desired saving in tons as a scenario parameter for the agricultural PE model. Environmental policies in the EU (e.g. ecological set-aside or organic

¹⁵ The global PE developed at FAO contains 32 commodities and 110 countries using FAOSTAT data.

agriculture) require a good global land use model. CGEs for climate change, emissions, food security and the energy debate would need to reconcile quantity balances of commodity, energy, nutrients and land. This would require a modification in the standard functional forms used in most CGEs in order to introduce functions that are able to reflect physical balances in an appropriate way.

While it might be technically possible to build into a CGE model the technical or commodity detail on a sector, this is most likely not a practical and effective strategy. Economists with CGE skills cannot realistically be expected to have accumulated the detailed engineering knowledge that goes into a specialist PE model. Fortunately, PE and CGE models can be linked without requiring the technical specialists who build PE models to have a deep understanding of GE modelling or the economists who build GE models to have a deep understanding of PE modelling. By linking PE and CGE, in an informal way, the engineering credibility of a PE is taken into a CGE (cf. Examples 1-3) and the CGE can spell out the implications for the rest of the economy of the PEs results. These results cannot be dismissed easily by people who are sceptical about the simple technological assumptions made by economists. While PE modelling can embrace technical depth on particular economic activities, it cannot stand alone. Policy makers need to consider the effects of sectoral policies on the broader economy. They need to think about macro effects (aggregate employment, GDP, the balance of payments, etc.) and effects on industries, regions and occupations. Quantifying these effects is necessary to avoid the tendency of PE modelling to give misleading impressions: either alarmist (as in Example 3) or overly optimistic (as in Example 2) (see the following boxes). Tracing out the economy-wide implications of sectoral policies requires a CGE perspective. Or stated differently: we can make PE analyses but we must think in GE terms to be sure that relevant economic mechanisms are also taken into account (Dixon, 2012).

Example 1: Combining PE and CGE analyses

NEMS is a PE model of the US electricity generation and distribution system (EIA, 2007). It incorporates information on every power plant in the US and a description of demands for electricity classified by industrial, commercial and household, and by region and season. These demands are specified exogenously or perhaps via price-sensitive demand curves. USAGE is a general equilibrium model of the US. It is applied by and on behalf of the US government on issues such as greenhouse gases, biofuels, trade agreements, immigration, the Obama stimulus package and the President's National Export Initiative.

For a given set of demands stretching forward to 2060, NEMS produces the least-cost paths for electricity generation and distribution. NEMS takes account of the costs of different fuels including the effects on these costs of taxes such as those designed to reduce greenhouse gas emissions. NEMS also accounts for investment requirements in switching between fuels. The prices of fuels, construction services and other inputs to electricity generation, power-plant creation and electricity distribution are specified exogenously. It is the exogenous treatment of demands for electricity and of input prices that makes NEMS a PE model rather than a GE model.

Example 2: Economic impacts of palm fronds

Results from PE analysis of the effects of different ways of using palm fronds (as inputs into electricity generation, the chemical industry, motor fuel production and the creation of energy pellets for export to Europe) were transferred to the general equilibrium model, MAGNET (van Meijl, et al., 2012). While the PE modellers introduced considerable expertise on technical issues surrounding the use of palm fronds as an energy source, it was not until the GE analysis was carried out that a sensible picture of the economic implications emerged. Whereas the PE analysis appeared to show strong benefits for the Malaysian economy from palm-frond projects, the general equilibrium analysis produced a far less sanguine picture. The GE modelling took account of economy-wide constraints on the availability of labour and capital. These constraints were missing in the PE analysis. Once economy-wide constraints were recognized, the energy-pellet option emerged as the least unattractive. The economic viability of this option was shown to depend on the future price of oil, the extent to which energy pellets would qualify in Europe as renewable energy, and the rate of improvement in the palm-frond-to-pellet technology.

Example 3: Australian greenhouse policies

A detailed description of a combined partial/general equilibrium analysis of Australian greenhouse policy is set out in Adams and Parmenter (2012). This work underlay the Garnaut Report (2008) and has been the subject of intense public debate. PE studies, centred on Australia's coal and other mining sectors, had given the impression that the introduction of greenhouse policies would cripple the Australian economy. General equilibrium analysis, which allows for resource movements and builds in adjustments in wages and the exchange rate, gave quite a different impression. Bolstered by Adams and Parmenter's general equilibrium finding that greenhouse policies have relatively benign economic effects, the Australian government has now introduced a carbon price with a \$23/ton tax on CO₂-e emissions by major polluters.

4.2 On the modelling of structural elements

It would be ideal if both PE and CGE models could be prepared to translate the evolution of the most important demand and supply long-term economic drivers into the system without requiring expensive re-specifications. It seems that most of the future uncertainties lie particularly on the supply side rather than the demand side. On the demand side, population growth is more certain than income growth. The demand side should focus in representing the expected preference shifts that are likely to take place in the global economy. This requires good empirical foundations especially in developing countries where consumer preference shifts are likely to play an important role.

The supply side should be able to depict the expected exogenous yield growth, one of the major sources of uncertainty for long-term projections (see, for example, conversion of the metabolism of food crops from C3 to C4). This would also allow for a better interaction with biophysical models when considering the adoption of new modern technologies. The structure of PE models is more conducive to the incorporation of technical engineering information (see previous examples). CGEs should improve the calibration of technological change across sectors and factors based on stylized facts supported by new econometric evidence. Specific attention should be given particularly to intermediate technological change in agriculture, food and biomass-using sectors. In addition, the physical flows in input-output tables should be reconsidered given that technological change can modify input-output matrix coefficients (e.g. representation of endogenous technological change).

The interaction with biophysical models can be obtained to different degrees, as explained in Witzke (2012). First, a 'soft linkage' can be obtained by checking the model results together with crop and animal scientists; if results are deemed technically unacceptable, this should involve further refinements. Second, 'hard linkages' can be established, for example by creating a link with expected yields provided by crop and animal scientists (Ewert et al., 2005) or by creating formal links to biophysical models defining the feasible space. Formal links can take place in optimization models (e.g. GLOBIOM, FASOM) or in synthetic models (e.g. CAPRI, MAGNET). A post-model linkage can also be envisioned where crop models are used to derive fertilizer and environmental implications from the results produced by the equilibrium model at hand. In this respect, the Agricultural Model Intercomparison and Improvement (AgMIP) project is an important exercise where climate scenario simulations for historical model intercomparison and future climate change conditions take place with the participation of various crop and agricultural economics modelling groups around the world.

The specification of production costs and competition between economic actors is better addressed within CGEs than PEs. PE models do not always consider all upstream and downstream sectors and assume perfect competition with exogenous margins. Imperfect competition has been explicitly addressed in several CGE applications (i.e. monopolistic competition). The DSGE model QUEST3 used by the European Commission's Directorate General for Economic and Financial Affairs (DG ECFIN) introduces monopolistic competition for profit-maximising firms. These firms pay an entry barrier to the intermediate goods sector by renting patent from the households, and government can subsidize the entrants and research. The need to depict market imperfection and contingency markets was especially highlighted by Gohin (2012) while for the other experts involved in this IPTS project it remained far from clear whether these factors should be more or less significant when looking at the long term. The majority of the experts consulted felt these were not the most urgent topics to be addressed by long-term analyses unless a specific focus on imperfect competition is required by the analysis of a specific sector or commodity.

A more careful consideration of capital and labour and their mobility would be relevant for many PE models and could lead to sensible improvements, even though explicit modelling may be limited by data quality. A better representation of factor prices is important especially for global analysis where the developing world is coming into the picture. In this case, the use of a CGE model or a PE model linked to a CGE model is recommendable. Regarding capital markets, improvements in CGEs could focus on international capital flows and on introducing dynamics for international investment and segmented capital markets. Long-term financial sustainability conditions should also be considered in a model for long-term projections. Labour supply in CGEs can be endogenized by allowing a consumption-leisure trade-off in the utility function and labour market segmentation could also be introduced. Further improvements can take place in introducing dynamics in labour mobility and wage adjustments and in making migration endogenous. The empirical evidence suggests that national labour mobility is nine times more prevalent than international labour mobility.

For land, the difference between PEs and CGEs narrows given that both modelling approaches normally rely on reduced forms for land supply (e.g. LEITAP). The introduction of a global land balance is another area for improvement, and CGEs may have a comparative advantage here compared to PEs. In this respect, empirical information should be collected to validate land supply functions. GIS information from satellites and regional land market modules could be retrieved and developed for key countries such as Brazil. This is crucial for biodiversity and indirect land use change (ILUC) impacts. Explicit representation of urban land, forestry land and other land is advisable

to ensure consistency in total area balance and eventually establish model linkages.

Water balances, currently not included in most models, seem to be equally tractable in both PE and CGE models, are a promising area for further model improvement.

A detailed regional disaggregation may facilitate links and interaction between different modelling environments including between different equilibrium economic models and between such models and biophysical models. Regional disaggregation can also help in assessing land extensification effects due to heterogeneous land parcels (see ILUC in Indonesia and Malaysia, multi-cropping in developing countries, e.g. Meijl et al., 2012) and a better representation of country-specific shifts in demand. A good solution is to have a database that can be disaggregated down to single countries even though the model usually operates on a more aggregate level (for example, the standardized GTAP database).

Armington-type representations of bilateral trade flows, given their 'stickiness', should probably not receive high priority in long-term analyses if this model feature was not already present in the modelling system adopted. Looking for explanatory factors for Armington elasticities may eventually help to enrich their empirical foundations since Armington elasticities will need to be adapted for analysing long-term impacts. Dynamic Armington elasticities could also help in this respect (i.e. MAGNET). Dependency on trade shares or explicit consideration of relative cost could also help to improve the trade representation. The representation of major trade developments as of today for long-term projections seems to be arguable given that current trade patterns cannot be extrapolated into the long-term.

A GE approach seems more conducive to representing structural change if the aim is to capture the evolution of changes in value added by sectors for a specific industry. In addition, because GE models have a formal representation of upstream and downstream sectors, they are supposedly better than PEs at addressing changes in the global distribution of production factors. Both GE and PE models are potentially well equipped to depict changes in trade patterns. It is important to stress that structural change either in a GE or PE framework will be the result of many concomitant interactions and therefore an endogenous result of the model that is difficult to influence and predict beforehand. Predicting structural change in trade patterns is hardly possible especially when considering changes in the internationalization of the value chain as well as the emergency of new products. Furthermore, structural changes that appeared in the past are not necessarily likely to persist in the future, and if they reappear they might not do so with the same intensity as observed in the past.

4.3 On the incorporation of technical features

4.3.1 What type of dynamics (or perhaps no dynamics at all)?

This section provides recommendations on the type of dynamics to be considered when performing long-term analyses. As suggested by Dixon (2012), if the focus is simply on the long term, a one-period calculation could suffice. In this case, the model could be used to answer questions of the following form (cf. Dixon, 2012): how different will the economy be in 2050 from the way it is in 2012 under explicit scenarios about population, technology, environmental policies and labour-force participation? Or specifically, for example, how will European standards of living and environmental quality in 2050 compare with those in 2012 if European fertility rates and technology follow their present trends while in Asian countries fertility rates converge to those of Europe and technological progress allows these countries to close half the technological gap with Europe? As outlined in Dixon (2012), to answer the example question, one needs to shock a model calibrated to 2012 with changes in population and technology representing those in the scenario for the whole period 2012 to 2050. However, if pictures of the intervening years are not needed, then it is not necessary to explicitly model dynamics. Thus, a formal treatment of dynamics is only necessary when we want to trace out the path of the economy between now and the long-term.

On the other hand, if the focus is on, for example, policies to restore macroeconomic health in the aftermath of the global financial crisis, then one usually must understand how stimulus policies are likely to affect business confidence and markets for labour and capital over the next few months and years (Dixon, 2012). This requires that lagged adjustment processes and changes in expectations are taken into account. Lags in expectations become irrelevant if the focus is purely on the long-term equilibrium, and not on the transition path to this equilibrium (cf. section 3). In addition, considering only the long-term horizon, the adjustment of variables to shocks can be assumed complete after (say) four decades. However, a purely long-term focus, especially when this refers to a real time scale of about four decades, will almost never be sufficient for policy making. So even if the long-term is the principal focus, one will normally want to know something about the transition path to the final equilibrium, especially the first few steps along it. This rises the question of what sort of dynamics are needed in an equilibrium model.

The most practical approach may be recursive dynamics (Dixon, 2012). This allows a model to be solved for period 1, then for period 2 using information on outcomes in period 1, and so on. Recursive dynamic models can contain realistic specifications of lagged adjustment processes in various markets, particularly labour markets (see, for example, MAGNET). A well designed recursive dynamic model will show how the economy adjusts to a shock in the

short term and then reveal the eventual long-run outcome. However, while recursive dynamics is practical and popular in policy work, it is not fashionable in academic circles (Dixon, 2012). As Dixon (2012) outlines, for academics the holy grail is model-consistent, forward-looking expectations. This is sometimes referred to as full dynamics. In models with recursive dynamics, agents make decisions in period t based on prices, quantities and other variables in period t and the evolution of these variables from earlier periods (lags). In models with forward-looking expectations, agents' decisions in period t reflect not only past and contemporaneous variable values but also values implied by the model for future periods. Thus for example, in a model with forward-looking expectations, a simulation of the effects of a carbon tax introduced in period $t+1$ but credibly announced in period t , will show agents cutting back on investment in the coal industry in period t .

The introduction of model-consistent, forward-looking expectations destroys the simple period-by-period sequential approach to dynamic computation. Period 1 cannot be solved until the solution for period 2 is known, but period 2 cannot be solved without the initial condition supplied by period 1. There are basically two approaches in the literature for exiting from this impasse. The first is to solve the model with all the periods treated simultaneously (see Wilcoxon, 1987, and Malakellis, 1998). This approach is feasible only for relatively small models. The second approach relies on iteration: period 1 is solved based on guesses for variable values beyond period 1. Then period 2 is solved based on guesses for variable values beyond period 2 and so on. Having solved for the whole sequence of periods the guesses are revised and the sequence resolved. Details of this approach are given in Dixon et al. (2005). This approach is only possible in a deterministic setting.

One of the problems in implementing a fully dynamic model as highlighted in Conforti (2012) is the availability of intertemporal substitutability parameters; they can probably be found for macro variable but are difficult to obtain for agriculture. The FAO has successfully developed a fully dynamic CGE model for Malawi with a focus on fertilizer use where a couple of sectors were represented. However, this experiment was limited to one country with two aggregate sectors. This highlights the risk that adding technical sophistication in the dynamic specification requires compromises somewhere else (e.g. regional and product coverage).

The recent IGEM approach developed by Jorgenson and Goettle (2012), although attractive to academic economists and to non-economists, seems to come at a high cost from the point of view of building a practical policy model. IGEM is an intertemporal CGE model comprising 35 industries in the US with a focus on energy and environmental concerns up to 2060. Each sector is characterised by a constant returns to scale translog production function that is estimated econometrically using time series data of input-output tables. The

model is spatial and follows an Armington approach where domestic and imported units are sold to all domestic agents assuming the same import-domestic mix for the commodities. On the export side, overspecialization is overcome by using a translog unit revenue function. On the import side, the Armington assumption circumvents extreme volatility in the import and domestic shares. The household demand for each composite commodity includes the effects of demographic factors, income distribution and shifts in preferences. During simulations, households are assumed to live infinitely and to have perfect foresight. The elements of the intertemporal utility function are consumption and leisure. Saving is directly connected to investment.

It has to be highlighted that stronger emphasis on econometric estimation than normally required in CGE modelling and more reliance on perfect foresight inter-temporal optimization are likely to come at a high cost. Among these costs are (a) high level of aggregation (lack of sectoral detail) to make econometric estimation possible, (b) implausible assumptions concerning the balance of payments, investment, saving and the terms of trade, (c) computing difficulties due to the theoretical (but not practical) necessity of imposing a long-run steady state. Thus, rather than emphasising econometric estimation, it is sometimes stressed that the use of expert information may be more important, especially in the context of providing policy support (see for example Adams and Parmenter (2012) in the context of the Australian government's decision to impose a carbon tax)

Fortunately, there are relatively few situations in which the use of model-consistent, forward-looking expectations is essential (Dixon, 2012). The most obvious is when analysing announcement effects. However, even in the rare instances where policies are credibly announced several years in advance, announcement effects can be ignored if the modelling focus is the long term. If the interest is on the effects of a policy in 2050, then the exact timing of the investment effects (which may be sensitive to announcements) between now and 2050 will be of secondary interest.

Dixon (2012) pointed out that there is a temptation to waste scarce research resources on fully dynamic modelling. A focus on full dynamics has sometimes led researchers to adopt assumptions, such as balanced growth, that simplify the implementation of full dynamics, but seriously sacrifice realism. Therefore it might be advisable to use fully dynamic models only sparingly.

4.3.2 Deterministic or stochastic?

According to Dixon (2012), the view of stochastics in policy modelling in general is naïve and uninformed. Econometricians have taught us to put confidence intervals around estimates. These confidence intervals reflect the stochastic properties of regression equations. Ideas from time-series

econometrics have been taken into CGE modelling by Pagan and Shannon (1987), Arndt (1996) and others. They perform repeated solutions of a model with elasticity values drawn from probability distributions. In this way, they translate confidence intervals applying to elasticities and other parameter estimates into confidence intervals for CGE results for the effects of particular shocks. For example, Pagan and Shannon (1987) recognised that Armington elasticities were important in determining results from Australia's ORANI model for the effects of tariff cuts on aggregate employment. By translating confidence intervals for Armington elasticities into confidence intervals for employment effects, they tried to answer the question: how confident can we be that a given tariff cut in Australia would lead to an increase in aggregate employment?

While this approach is seemingly attractive, it has been of limited practical value (Dixon, 2012). The problem is that detailed CGE models contain an overwhelming number of elasticities and other parameters and very few of these are supported by confidence intervals based on stochastic econometric specifications. In addition, the introduction of stochastic terms may require a lot of short-term detail to be introduced in a long-term model, perhaps through a risk parameter, although this may add a burden to the model with unsure information at the margin (Conforti, 2012). Even when confidence intervals have been computed for model results, they may not be appropriate. In fact, they may disguise much more fundamental problems than parameter uncertainty. For example, Ratto et al. (2009) show carefully worked out confidence intervals from a DSGE model for the effects on macro variables of stimulatory policies in the Euro zone. While not mentioned by Ratto et al. (2009), the critical point concerning their results is that they were derived as a deviation from a steady state reflecting normal levels of employment and capacity utilization. Despite an impressively narrow confidence band, the estimates are likely to be misleading as an indicator of the effects of stimulatory policy in the recessed conditions that now prevail in much of Europe (Dixon, 2012).

Modellers must recognize that results are subject to uncertainty. But if formally derived confidence intervals have limited applicability, then what should modellers do? An approach that has been found effective on several occasions is the presentation of sensitivity analyses accompanying the results of the main simulation scenarios (Dixon, 2012). Of course, this requires skill in identifying and qualifying the main sources of uncertainty around the final results.

4.3.3 Incorporation of variable and time-dependent parameters, variable returns to scale, non-homothetic functions, time-dependent autonomous adjustments and new substitution possibilities

The evolution of the major economic drivers of supply and demand is an important element involved in long-term dynamic adjustments. In order to model this evolution, appropriate choices in terms of flexible functional forms and parameters are needed. Models may also need to use more flexible forms to depict elements like the information cost of switching from one technology to another. The CDE consumption function popular in the GTAP model is not suitable for dynamic models because it has relatively constant income elasticities and very small cross-price elasticities (i.e. low substitution elasticities). Flexible demand systems, such as AIDADS, may be particularly suitable for this purpose as well as 'LES' or generalised versions like the GL indirect utility system (Ryan and Wales, 1999). The CES production function popular in CGEs, although easy and parsimonious, has several limitations that should be addressed in future model improvements. Improvements in intermediate demand representation are also deemed to deserve attention since in the long-term the upstream demand (i.e. inputs) may develop differently to the downstream demand (i.e. outputs).

Given the high uncertainty in both parameters and exogenous drivers when addressing the long term, any additional equation that ties together the endogenous variables in a reasonable way can be considered helpful for both PE and CGE models. In this respect, micro- and macroeconomic constraints could be useful as could technical relationship. Technical relationships that can be recommended are: balances regarding projections of beef and milk production to ensure they remain consistent with the supply of calves into production chains; balances on milk fat and milk protein in the dairy sector (e.g. CAPRI, AGMEMOD, CAPSIM) to ensure that derived products match raw milk production; balances on crop nutrients to link fertiliser use, crop production, and manure output from animal production (CAPRI, GLOBIOM); balances on feed energy and protein to impose the feed requirements of animals. Similar consistency rules can also be imposed for human consumption (e.g. MAGNET). The global PE model at FAO, for example, has a feed use input/output matrix conveying the technical parameters that define the unit use of feed products per unit of livestock products. Water balances can also ensure that water use is consistent with the extent of irrigated areas (see the IMPACT model).

These relationships can be included in a 'soft' or strong form. For example, a weak form of energy balance is included in the current FAO modelling of feed demand through the calibration of demand elasticity for feed and in a very similar fashion for food demand in the CAPRI system. A stronger form would

involve an additional model equation, which should allow for some degree of 'normal' food waste by animals or humans. An extra model equation would maintain the balance in all simulations whereas with the calibration approach the balance may not hold as we move further away from the calibration point.

A clear distinction between medium-term and long-term elasticities should be also considered when addressing long-term projections. Flexible response parameters should be considered on both the demand and supply sides. Production substitution elasticities are very important. They reflect short-term rigidities and should also take into account long-term flexibilities. The responsiveness of the long-term parameters is expected to be greater than that of the shorter-term parameters. Currently, in most equilibrium models with a focus on agriculture, elasticities are constant and specified for a medium-term horizon.¹⁶ Not adapting consumption elasticities to the long run is likely to cause imbalances in calorie intakes (Meijl and Woltjer, 2012). One way that diets remain 'plausible' is through setting substitution elasticities so as to limit substitutability between different classes of food characterized by different protein and energy contents.

4.3.4 Forecasting errors and checks for forecasting ability

Perhaps the most common reaction of policy makers and advisors when presented with results from an economic model is: 'how do I know these results are valid?' Dixon and Rimmer (2012) explain that validation can be of several types. The simplest type of validation is a verification that results have been computed correctly, i.e. that they follow from the model's theory and data. A second type involves demonstrating a model's consistency with recent history. A third type of validation evaluates a model's forecasting ability (see Example 5) and a fourth type involves checking that a modeller's explanation of results is a legitimate reflection of the way the model works. The third and fourth types are discussed in this section.

Early CGE modellers were interested in the forecasting ability of their models. For example, Johansen (1974) reports a validation test in which projections for 1950 to 1963 covering output, capital, labour and prices were compared sector by sector with reality. In a similar vein, Taylor et al. (1980) highlighted the performance of their model in reproducing industry growth rates for an historical period (1959-71). Similar tests were carried out by Dixon et al. (1978) and Cook (1980). Subsequently, CGE modellers concentrated on comparative-static analysis of the effects of particular shocks: for example, how would a given change in tariffs affect the economy? However, as the economy is subject to many shocks simultaneously, comparative-static results

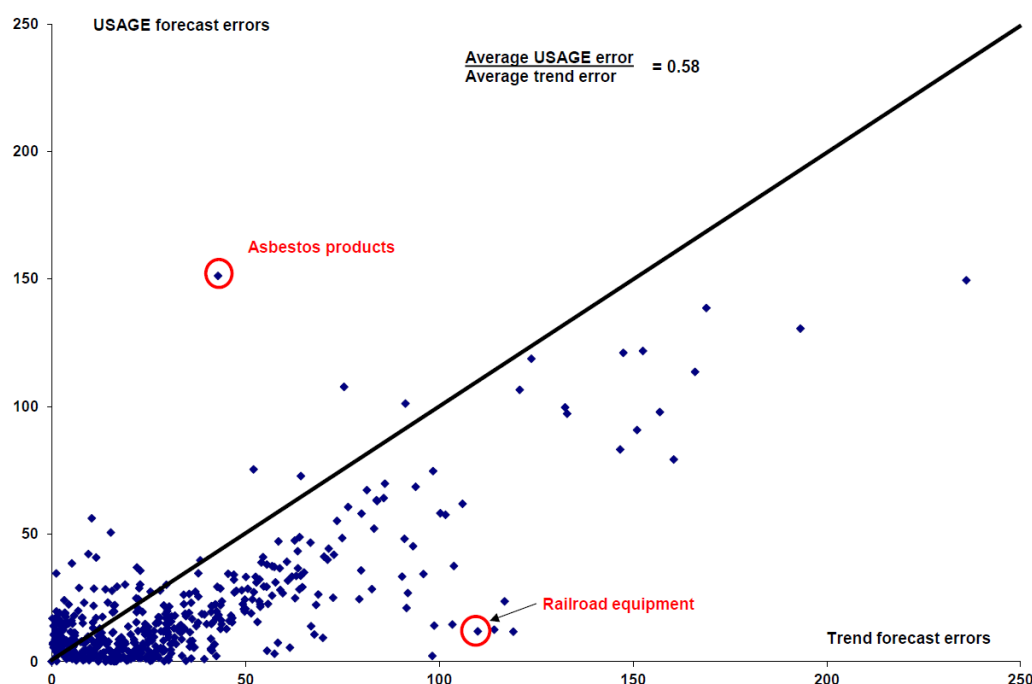
¹⁶Long-term elasticities have been implemented in MAGNET for the labour market based on econometric estimates but the same idea should be implemented also for other markets.

for the effects of particular shocks cannot be validated (or contradicted) by comparison with the historical record.

In recent years CGE modellers have used their dynamic models to produce what they hope are realistic baseline or business-as-usual forecasts. This re-opens the merit of using forecasting tests as a means of validation. Example 4, taken from Dixon and Rimmer (2010), shows results from such a test in which USAGE forecasts for 500 U.S. industries were generated for 1998-2005 using only data available in 1998.

Example 4: Percentage forecast errors for industry outputs, 1998-2005

Figure 1, taken from Dixon and Rimmer (2010), shows results from such a test in which USAGE forecasts for 500 US industries were generated for 1998-2005 using only data available in 1998. These forecasts were compared with forecasts for 1998-2005 based on trends from 1992 to 1998. As shown in the figure, most of the industry dots lie below the 45-degree line, indicating that USAGE does better than the trend forecasts. The average USAGE error was only 0.58 times the average trend error. Research is now continuing on outlier dots. Why did USAGE do so badly for asbestos products? On the other hand, why did USAGE do so well for railroad equipment?



Forecasting performance is usually the first thing that comes to mind for non-modellers when they think of validation. However, Dixon (2012) pointed out that for equilibrium models the most important form of validation is the fourth type listed above: effective modelling depends on the ability of modellers to explain their results. This type of validation is vital in assessing what has been taken into account in an analysis, whether the model's data on the parts of the

economy with which the analysis is concerned are up-to-date and accurate, and whether the mechanisms built into the model are an adequate representation of how the relevant parts of the economy behave.

4.4 On the other methodologies and theories

4.4.1 On the use of DSGE

The case for DSGE modelling rests on how important it is to describe the full time path. The more one wishes to know about the short term, the more useful it is to model this correctly using DSGE models. Wickens (2012) stressed that DSGE models are unlikely to be very useful when analysing the demand side unless the financial aspect is important, i.e. borrowing. However, DSGE models will be much more relevant for supply-side decisions, especially where they involve long time lags as do tree crops, animal rearing and capital decisions. Given the diversity of agricultural commodities, DSGE models would have to take a PE approach. The components could then be assembled into individual commodity models, and country, regional or trading block models. Where there are world markets, eventually this will be the appropriate level of aggregation. Bukowski (2012), points out that the agricultural sector seems to be suited equally well to DSGE modelling as any other part of the economy.

As agriculture is only a small component of most (EU) economies, but the macro economy impinges heavily on agriculture, it would probably be necessary to incorporate a macroeconomic model or the predictions from such a model. The macroeconomic model could be 'off-the-shelf' rather than newly constructed. The most difficult part would be assembling all of this into a single model.

Following Wickens (2012b) the best strategy is likely to lie between one of two possibilities: (1) construct models of individual agricultural commodities for each region which interact on world markets and are affected by both local and global macroeconomic forces - this may entail regions exporting only their surplus over what is consumed domestically; (2) construct world markets for each commodity by aggregating demands and supplies for each commodity and relating domestic prices to world prices where any domestic tariffs will play a role. In practice, the current agricultural system would be a mixture of the two with commodities organised according to one or the other of these polar possibilities. A key question is the relative importance of the dynamics of individual commodities and the GE interactions between commodities. The more important the former, the more relevant is DSGE modelling likely to be.

Practical numerical limits on the number of variables that can be included in a DSGE model depend on the programming environment selected. Large-scale DSGE models can nowadays comprise 50 thousand variables. The dynamic

stochastic optimization problem using symbolic language can be rewritten in the form of a dynamically constrained optimization problem. One limitation of DSGE for application to the agricultural sector could be in the intended regional and product resolution since the number of countries will need to be multiplied directly by the number of variables in a single country. Bukowski (2012) points out that if some compromises on the complexity of the model at the country level are made, it would be possible to construct 3-6 country models reflecting the representation of major (EU) agricultural trading partners and policies. DSGE shortcomings are mostly related to their level of complexity and to the fact that for the long term they become less relevant since the assumption of a perfect foresight turns to be unattainable. Furthermore, given that the DSGE solutions are a continuous approximation around a fixed steady state, some economic features cannot be easily addressed such as minimum wage, new sectors or binding edge-like resource constraints. However GHG and abatement policies, climate change and water scarcity can be addressed in a DSGE framework. For example, the endogenous technological adaptation of economic agents to climate change and water scarcity as well as the emergence of new substitution possibilities can be introduced (Bukowski, 2012).

4.4.2 On the use of optimal control

The recommendation is to start by simple incorporating several endogenous dynamic factors into an equilibrium model. The use of OC should be confined to addressing aggregate problems. Control feedbacks come from the state vector and the state vector consists of all variables in the model. So in the case of disaggregated agricultural sector mode, the state vector could contain many thousands of variables, which would lead to infeasibility.

Assuming that OC is applied at a sufficiently aggregated level, one could use time series data to calibrate differential equations describing these dynamic endogenous factors that can be treated as drivers of long-term dynamics. At this level one can also test the adequateness of the dynamics and specify the aggregation procedure. Aggregated constants could be also calibrated to these historical data (i.e. discount rates, amortization factors, restrictions, etc.). In case appropriate data are not available, sensitivity analysis could be performed at this level. The idea is to split the problem into different time dimensions. Equilibrium models can address short- and medium-term shocks whereas OC can complement equilibrium models for the long term (Krasovskii, 2012). The major challenge is reconciling the different approaches that should develop in parallel. Short- and medium-term equilibrium model results could be aggregated to driving factors of an economy to a new state following OCT.

Given its usual aggregation level and long time horizon, OC is particularly suitable as a complementary tool providing global dynamics for long-term

horizon. As such the OC model would generate long-term dynamics that would determine the dynamics of the equilibrium solutions obtained with equilibrium models. Equilibrium models would use a feedback rule to provide the control model with aggregate factors derived from the short- and medium-term results. These aggregate factors would affect the dynamics of the control model and consequently the long-term forecast to provide the new steady state for the equilibrium model. Based on this, the equilibrium model would be used to analyse structural policies in the neighbourhood of the new equilibrium (Krasovskii, 2012).

Incorporating OCT into the long-term modelling approach would require the development of an appropriate OC model and its linkage to an equilibrium model. Krasovskii (2012) outlines the following steps for model development: (1) identify the state variables subject to differential/difference equations; (2) specify the control variables needed (e.g. investment, saving, etc.); (3) specify the single or multiple objective functions that drive the model solution over time; (4) specify initial and terminal conditions for the system which could define certain domains to be reached at given moments in time; (5) determine the time interval; (6) define the model parameters. The steps for linking the OC model to an equilibrium model are: (1) specify which variables in the control model are aggregated from the equilibrium model; (2) decide which parameters are endogenous and exogenous in each model; (3) define an aggregation procedure and a synchronization step in the joint time process.

5 Conclusions

Given the methodological requirements for long-term modelling, one important question regards the strategy for model development. More specifically, is there a need to start afresh and build a new model from scratch, or would it be sufficient to modify and extend existing models? Tackling this fundamental question from the perspective of IPTS, it was the general opinion of the consulted experts working on PE and CGE models that a complete overhaul of the modelling tools necessary to examine long-term modelling questions was not deemed necessary, or indeed advisable given the accumulated knowledge in agro-economic modelling already in place at this institution. Furthermore, even if IPTS were convinced that PE and CGE modelling needed a completely fresh approach to make it suitable for their purposes, the obvious starting point would still be one of the existing global models, for two distinct reasons. On the one hand, a sound in-house knowledge of the programming language (i.e., GAMS or GEMPACK) as well as the behavioural assumptions provides an important advantage when exploring feasible modelling innovations in the PE or CGE framework in order to answer specific policy questions (i.e., long-term modelling). Moreover, the data work in the existing suite of IPTS models embodies many person-years of research effort and knowledge, which is a crucial element when looking into the black-box of any given model structure and providing policy relevant and plausible model results. For these reasons, the main candidates as possible starting points are those models already included in iMAP, such as GLOBE and MAGNET on the CGE side and AGLINK, CAPRI and ESIM on the PE side.¹⁷ Anecdotal evidence from experienced modellers illustrates the merits of the above arguments. Indeed, many interesting modelling applications are non-standard, requiring data and behavioural specification that are not already present in existing models. For example, to study unauthorized immigration in the US Dixon (2012) had to modify an existing CGE model to include decisions by potential immigrants to cross into the US illegally and decisions by US employers to employ them. Similarly, for studying a shortage of water for irrigation in Australia, it was necessary to extend an existing CGE model so as to include decisions about reallocation of irrigable land between irrigation and dry-land activities. When LEI wanted to look at the implications of an environmentally motivated policy of permanently banning agriculture from large tracts of land throughout the world, it had to modify an existing CGE model to introduce land-supply curves that could be shifted inwards as part of a CGE simulation. So, with regard to adaptation or developing a new model, there is no need to reinvent the wheel, but there is plenty of scope for modifying it for new purposes.

¹⁷ For a recent description of iMAP see M'barek et al. (2012).

When addressing the long term, the major issues seem to be the availability of relevant parameters and the formulation of appropriate behavioural assumptions. For determining the appropriate modelling structure simulating long-term effects of policies, an initial narrow focus is necessary for the IPTS. This is likely to require a selective and incremental approach in addressing the specific issues at hand. As a starting point, the exercise should be guided by the demands of policy makers. In GTAP, the initial focal issue was on trade policies. In the opinion of the experts consulted for this project, researchers should not be set the vague task of building a general 'ideal model' following a 'one-size-fits-all' approach but rather follow a more parsimonious and selective approach where the endogenous information to be acquired from the model is balanced with the exogenous assumptions and parameters required by the model. In this way, a policy-relevant model is likely to emerge as part of the solution of the specific problem to be addressed. Once a model is built for relevant and specific analyses, it is likely that the same model can be further adapted for a much wider range of issues.

The alternative approach of establishing a more general economic model would be to build a general-purpose framework in isolation from urgent policy matters. As pointed out by Dixon (2012), a problem with this approach is that researchers may then respond to the criteria of academic publishing and the imperative of academic promotion. These criteria include technical novelty, adherence to current academic fashion, succinctness and ability to impress peers with erudite verbal and written exposition. None of these criteria is necessarily important for the creation of a policy model. Such a model requires the application of economic theory that is relevant rather than novel or fashionable, detailed data work with meticulous and complete documentation rather than succinctness, and a willingness to elucidate, via simple back-of-the-envelope arguments, rather than a desire to impress via erudition. Practical policy models cannot be built without a major input from talented academics. Consequently, tension between academic work and practical work for the creation of policy models could be a problem. To recruit academics, policy administrations must provide an open environment in which academics can participate in conferences, provide training and publish (possibly with a lag) even sensitive material.

When the focus is on the long term, the standard policy focus on specific counterfactual experiments should be changed, capturing stylized facts on a more aggregate level by carrying large-scale experiments (e.g. complete free trade) in order to prioritize relevant strategic areas for future analyses and program specific activities. This strategy is also currently pursued at the FAO in the Global Perspective Studies team of the Agricultural Development Economics Division when performing long-term analysis that provides support to member countries. A policy focus in agriculture normally refers to a

medium-term horizon of about 10-15 years that clearly differs from a long-term horizon defined in real time for about 40-50 years. At the same time, it is hard to believe that the same policy in place today will last unchanged forty years from now. It is also difficult to support a long-term policy analysis without considering incremental changes and evolutions in policies.¹⁸ An ambition to perform baseline projections up to 2050 seems to go far longer than normally required for economic agents to fully adjust to a policy shock. Thus, the main research focus differs from that of the typical medium-term policy scenario analyses carried out by IPTS.

The inherent large uncertainties related to the long term (e.g. the development of oil prices) challenges the standard modelling tools for policy analysis. Scenario analyses (i.e. different world views) around key uncertainties might be an alternative way to conform for example with the Special Report on Emission Scenarios of the IPCC rather than implementing more complex fully stochastic models. Incorporating uncertainty from the start into scenario analysis prevents potentially misleading messages to policy makers. Key uncertainties relevant for the future could be: the introduction of new bio-based technologies and sectors that substitute for fossil energy-based products, water viewed as one of the most important limiting factors for yield growth (e.g. salinization problems in developing countries), a sustainability focus versus a current profit-oriented focus, globalisation versus regionalisation, and different level of oil price. In addition, the addition of a 'no-regret' policy option in the various scenarios seems to be an interesting option. Given the lack of certainty underlying many of the elementary factors relevant for long-term developments, considerable recourse to empirical knowledge generation is required. In this respect, specific micro econometric studies may provide part of this required empirical knowledge. The more flexible a modelling approach is, the more it will be possible to include external knowledge. Flexibility can be achieved formally in the model structure and behavioural equations as well as in terms of regional and product coverage and disaggregation. Key choices relate to the selection of well-chosen flexible specifications able to capture relevant dynamics and the definition of the required sectoral and regional details. Key data and parameters should be identified considering the policy questions to be addressed in order to find which data and parameters need to be improved. Finally, modelling outputs need to be easily interpretable and plausible, and to provide policy relevant insights for policy makers. The easier modelling results are to communicate to policy makers, the more useful they will be in supporting the decision making process.

¹⁸ A good example within the CAP is the milk quota system. When it is abolished in 2015 it will have lasted for more than 30 years, which makes it one of the longest-running policy instruments in the EU. However, since its introduction in 1984 the milk quota system has changed considerably due to successive adjustments.

The rest of this chapter provides a point-by-point summary of the main findings of the consultant expert meetings regarding the specific major methodological issues for long-term analyses:

Choice between a PE or CGE approach. The recommendation is to use both. The direction of communication as well as the degree of formal linkage between the two modelling approaches (from PE to CGE or from CGE to PE) will depend on the questions to be addressed. For example, a PE model can generate expert engineering information that can be fed into a GE model. Similarly, GE results can be transferred to a PE model to obtain more disaggregated results in terms of products and regions. Due to their cross-sectoral consistency GE models are better suited than PE models for addressing biofuels, climate change and factor markets as well as global analysis with a focus on developing countries. These aspects seem particularly relevant when having a long-term perspective.

Representation of demand and supply based on sound micro- and macroeconomic foundations. Most of the currently available MCMR models focusing on agriculture represent consumer demand, supply and feed demand decisions in a theory-consistent way. However, more effort should be invested in better representing exogenous shifts. The largest sources of uncertainties in the future are expected to be more on the supply side (e.g. exogenous yield growth resulting from the introduction of new plant metabolisms). Therefore, a modelling structure able to interact flexibly with biophysical models (crop models, forestry models, ruminant models and nature conservation) is likely to be better equipped for representing exogenous shifts. The introduction and use of flexible functional forms and of micro, macro and physical constraints are deemed essential for capturing dynamic adjustments and for coping with the sources of uncertainty embedded in long-term projections.

Specification of production costs and representation of competition between economic actors. It is considered that these elements are better addressed in a GE framework. Therefore, use of a GE is recommended when production costs or competition demand explicit treatment. No unambiguous conclusions were reached on the relevance of the treatment of imperfect competition and contingency markets when addressing long-term projection although for most experts they seemed to be an issue of secondary importance.

Inter-sectoral and regional factor mobility. GEs are considered to be better equipped than PEs to address this, due to their endogenous representation of factor markets and their scope for tackling imperfect mobility. The introduction of global balance on land use is one source for improvements as well as the introduction of dynamics for labour mobility and international capital flows. Water supply seems to be currently absent or at

most only partly captured in existing MCMR models with a focus on agriculture. This aspect seems to be linked with the representation of structural change in a global agriculture.

Representation of trade partners, agricultural and trade policies and major trade developments. The experts point out that for the EU a disaggregated trade representation (at least to country level) may become useful for linking models for different purposes. The 'stickiness' in Armington-type representations of bilateral trade should be improved by selecting long-term trade elasticities, if the aim is to keep a bilateral trade representation in the long-term. However, if some simplification needs to be imposed in order to accommodate other complexities arising from long-term projections, it seems that this could be done in the area of trade representation. Moreover, major trade developments seem to be difficult to anticipate and predict 40 years from now.

Structural change in global agriculture. GE models explicitly represent upstream and downstream sectors and are therefore probably better equipped than PE models to capture and depict changes at different levels in the supply chain. However, as with PE models, GE models rely on the assumption of an average representative economic agent. DSGEs can also provide a detailed representation of different economic agents such as government and banking sectors.

Incorporation of dynamics. The experts' advice is to begin very simply by focusing on representing demand and supply drivers for the long term relying on flexible behavioural functional forms able to capture major changing patterns in consumption and technology through the relevant parameters and elasticities. Regarding the choice of fully dynamic or recursive dynamic, the expert recommendation is to use neither if the focus is *only* on the long-term equilibrium. Nevertheless, a formal treatment of dynamics is necessary when we want to trace out the path of the economy between now and the longterm. In any case, fully dynamic analysis should be used sparingly because of model complexity and computation time that currently limit their application to models with large regional and product disaggregation. Full dynamic models are particularly appropriate when looking at intertemporal decisions (i.e. investments, capital and several financial decisions) and policy questions on the appropriate timing of a policy (i.e. announcement effects). The recursive type is arguable for the long term when the adjustment to shocks will be completed and it seems more appropriate for medium-term analysis where the focus is on the path of adjustment to a new policy. However, recursive dynamics may help to generate the difference between short-term and long-term effects.

Whether to use a deterministic or stochastic approach, the majority of consulted experts recommend deterministic, supplemented with common-sense, tabular presentations to highlight critical aspects of uncertainty. In MCMR models with a focus on agriculture, the large number of parameters may not allow a full incorporation of stochastic terms pushing for a selective approach where uncertainty is introduced only for some key relevant parameters or crucial aspects. This is why most applied agricultural PE models that include stochastic terms (e.g. FAPRI, ESIM, AGLINK-COSIMO) are defined partly in stochastic terms. A full incorporation of stochastic terms for all activities in a PE model has not yet been reached, but so far was also not requested as the demands from policy makers have singled out particular uncertainties that were deemed to be very important. However, if policy makers would ask for all potentially uncertain elements in the model to be treated stochastically, this would be rather technically infeasible, because they are considered to be computationally intractable, whilst there is a need to understand the source of stochasticity to which one wishes to focus. Uncertainty may refer to parameters (i.e. response coefficients, elasticities, etc.), to variables (i.e. crop yields, exchange rates, crude oil price, etc.), and to behavioural equations (e.g. food grain demand and food grain yields). In addition, given the integration between markets, it is likely that the shocks are correlated at regional and global level and not considering the contemporaneous regional correlation could underestimate the uncertainty. The role of risk was not explicitly considered among the methodological issues relevant for this project.

Incorporation of variable and time-dependent parameters. The scope for allowing for variable returns to scale, non-homothetic functions, time-dependent autonomous adjustments and new substitution possibilities, the experts highlight that these aspects are partly set when selecting flexible functional forms and introducing consistency constraints (as discussed in section 2.a). A crucial point is the need to differentiate the underlying demand and supply elasticities used for the long term and this also holds for substitution elasticities. The use of time-varying or drifting parameters requires the availability of long time series. Non-homothetic functions in preferences or sector biased technical change have been introduced in the GE framework and their use will depend on the questions one wishes to address. Autonomous adjustments are a model outcome. New substitution possibilities will be difficult to predict unless the empirical evidence is available.

Use of forecasting errors and checks for forecasting stability. It was emphasized that validation is important and necessary. However, the expert recommendation is to perform validations, especially sensitivity analyses, because the use of forecasting errors and checking for forecast stability do not seem to match the nature and purpose of equilibrium projection models.

‘New’ methodologies and theories (DSGE and OCT). DSGEs are attractive when intertemporal decisions and the stochastic dimensions become relevant. The applicability and the advantages of DSGE models compared to CGE are evident especially for the short term. However, the superiority of DSGE for long-term analysis is far from being an established fact. It is true that DSGE models contain forward-looking terms of endogenous and exogenous expected future values. However, by design the DSGE solution eliminates the future expected values of all endogenous variables. Therefore the final solutions strongly rely on the forecasted exogenous variables also available to other types of models. This raises the question of what would be the additional information content used and provided by DSGEs as compared to other models. Their application has been confined up to now to very aggregated types of analyses e.g. of monetary policies, where there are only relatively few instruments and monetary targets. This is in contrast with the fairly disaggregated commodity-specific resolution encountered in the CAP. The recommendation is to implement and test macro-econometric DSGE models for specific satellite case studies where investment decision and uncertainty matter (e.g. animal long-term herd management strategies) for the supply dynamics. Another option could be to carry out a very aggregate analysis only keeping two aggregate sectors (e.g. agriculture versus non-agriculture) for a number of limited regions. One issue to address is the selection of a relevant time span for the analysis in order to make short- and medium-term dynamics relevant for a longer time span given that the advantage of DSGE resides particularly in the short-term dynamics. Regarding OCT, it was pointed out that OCT assumes a known system can be optimized. However, given the large number of uncertainties when facing long-term analyses, the use of OCT seems to be not pertinent and could lead to technical infeasibilities. However, it could be relevant for climate policy but only for relatively simple models due to the curse of dimensionality that limits its applicability to large-scale problems. Simple control rules could be utilized such as price responding over time to the difference between demand and supply. OCT rules can also be utilized to validate stylized facts where total factor productivity can be used to inform the technological trajectory as in the DICE control problem where investments act as a control variables.

In general, the decision about which methodology to use should be driven by the purpose of the long-term projections. Therefore, it is important to determine the focus of long-term analyses for a policy-support organization like the JRC-IPTS. A crucial question is whether the focus of the analysis is on the distant end-point, where different world views about the future can be benchmarked, or on the time path leading to the end-point. Another crucial question is whether the focus is on the assessment of the long-term impacts of

interim results. This type of focus would imply a Bayesian updating mechanism where medium-term interim results are allowed to update the long-term baseline eventually modifying the projected end-point.

The communication and interpretation of results is crucial for a policy-advising institute like the JRC-IPTS,. Therefore, models for long-term analysis should be judged on their outputs and their ability to provide plausible, policy-relevant insights and not by the apparent fanciness of their inputs.

It is important to point out that only a limited number of methodologies are considered in this report, some of which are available in the current suite of iMAP models at the JRC-IPTS while others are not. Likewise, a small number of experts were invited to join this advisory project and therefore the general recommendations in this report reflect their biases and expertise. Consequently, the methodologies considered clearly represent a non-exhaustive subset of all potentially available options.

An additional modelling framework that could deserve attention is agent-based modelling, which is a combination of DSGE and CGE modelling where the forward-looking character of DSGE is combined with the CGE disaggregation. Several international projects (e.g. AgMIP, Global Futures for Agriculture) are currently focusing on linking biophysical models with economic models. This requires a synchronized investment in different fields: breeding, genetics, crop and animal sciences, GIS, and economics. The challenge is how to translate, use and incorporate the information of the different fields in a unified modelling framework. The GLOBIOM recursive dynamic PE model developed at IIASA incorporates great engineering detail with spatial and economic details in interaction with biophysical models that include crop, forestry, ruminant and natural conservation models (e.g. EPIC, G4M).

During the discussions within the project, it emerged that most sources of uncertainty are on the supply side and this is likely to be particularly important in the developing world. A global perspective seems indispensable when addressing long-term projections and European policy advising organizations will need to cope with the requirement of having reliable quantitative information from developing countries. This will require a considerable investment with local institutions for the exchange of economic and biophysical quantitative information. Finally, the consulted experts recommend a Pan-European model intercomparison. The development of a small European exercise across Europe comparing projections in a systematic way from different modelling system could be a useful learning exercise and could lead to ideas about how to integrate different modelling environments for long-term projections. This comparison could be driven by policy-advising institutions like IPTS with the support of several key universities.

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Abstract

Food security, natural resources and climate change related questions focusing on a longer time horizon (2050+) are gaining importance. To assess the requirements and challenges entailed with the simulation of long-term issues in the agri-food sector the JRC-IPTS carried out the project "Methodological requirements of a modelling tool for simulation of long-term (2050) effects of policies affecting the agricultural and food sectors", involving experts for different methodologies. Partial and General Equilibrium models are covered as well as Dynamic Stochastic General Equilibrium (DSGE) and Optimal Control Theory (OCT) approaches are taken into account, evaluated and discussed.

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